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HOW EXTENSIVE IS INTER-STATE DIVERSION OF RECREATIONAL MARIJUANA?

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How Extensive is Inter-State Diversion of Recreational Marijuana?
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ABSTRACT

Despite federal prohibition, recreational marijuana is available to 21% of the United States population. A chief concern among policy makers across multiple levels of government and political parties is inter-state diversion of marijuana from states with legal markets to others. We measure this diversion with a natural experiment. Oregon opened a recreational market on October 1, 2015 next to an existing market in Washington, which opened on July 8, 2014. Using comprehensive administrative data on the universe of Washington sales, we find Washington retailers along the Oregon border experienced a 41% decline in sales immediately following Oregon's market opening. Retailers along Washington's borders with Idaho and Canada experienced no such decline. The decline occurred equally across weekdays and weekends, and was largest among the largest transaction sizes, suggesting diversion, not drug tourism, was to blame. Our estimates suggest that 11.9% of the marijuana sold in Washington was diverted out of the state before Oregon legalized and 7.5% remains diverted today.

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1 Introduction

The majority of Americans support legalizing marijuana[1] and eight states with 21 percent of the U.S. population have or will soon have legal, taxed, and regulated markets for recreational marijuana. Despite this, marijuana is still classified as a Schedule I drug under the Controlled Substances Act.[2] The Department of Justice has de-prioritized enforcement of the federal marijuana prohibition under the expectation that states will work to further the Department's overall priorities. Chief among these is "preventing the diversion of marijuana from states where it is legal under state law in some form to other states" (Cole, 2013). Indeed, inter-state diversion of marijuana has been a key concern of policy makers from the local level to the Supreme Court since legalization efforts began in the 1970s. Politicians from both major political parties have expressed concerns about the possible spillover effects of legal markets, and Attorney General Jeff Sessions has identified diversion as a key issue.[3]

Despite this focus, the extent of diversion and drug trafficking is unknown – as an illegal activity, it is difficult to measure, much like tax evasion (Slemrod & Weber, 2012), insider trading (Meulbroek, 1992) or discrimination (Bertrand & Mullainathan, 2004). We exploit a unique natural experiment in the Pacific Northwest to provide the first estimates of the extent of inter-state diversion of recreational marijuana. Washington opened a market for recreational marijuana on July 8, 2014. Oregon chose to follow suit shortly thereafter, and Oregon's market opened on October 1, 2015. Using administrative data on the universe of recreational marijuana transactions at the daily level in Washington, we estimate the change

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[1]http://www.cnn.com/2017/04/20/politics/marijuana-poll-legalization/index.html

[2]Drugs within this classification, such as marijuana, heroin and methamphetamines, are considered to have "high potential for abuse" and "no known medical benefit."

[3]http://www.cbsnews.com/news/pot-legal-states-scramble-to-curb-a-major-threat/

in demand for marijuana along Washington's border with Oregon caused by Oregon's market opening.

We find the quantity of marijuana[4] sold in Washington-Oregon border counties (measured by weight) falls by 41% when Oregon's market opens. This result is almost entirely driven by firms located within 25 miles of a border crossing[5], which experienced an average decrease of 44%. We find the largest declines in counties that provide the nearest retail locations for the largest portions of Oregon's population. At the time of this drop in marijuana demand along the Oregon border, marijuana demand in the rest of the state, including along Washington's borders with Idaho and Canada, was unchanged.

If, instead of diversion, we believed the activity along the border was driven by tourists who purchase and consume marijuana within Washington's borders, we would expect a larger effect on the weekends, but we find no such effect. Moreover, we find the largest declines for larger transactions, consistent with the hypothesis that Oregonians are purchasing substantial amounts to bring back to Oregon before Oregon's recreational market opened. Our results are robust to a number of alternative specifications and approaches, including estimating equations derived from regression discontinuity and difference-in-differences designs.

We apply our diversion rate estimates directly to the quantity of marijuana purchased in Idaho border counties and conclude that prior to Oregon's market opening, 11.9% of marijuana sold in Washington was diverted to other states. In the two months after Oregon opened, about 7.5% of marijuana was diverted, totaling 445 kilograms of the substance. We

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[4]Here and throughout, we discuss only 'usable marijuana' as defined by Washington law, which consists of the dried and cured flowers of the cannabis plant, and is consumed by smoking. While other derivatives of the cannabis plant are available, usable marijuana comprises the vast majority of the market by transaction count and revenue.

[5]Approximately 75% of the Oregon-Washington border is formed by the Columbia River (Holmes, 1998).

use these numerical estimates to consider the implications for potential state- and federal-level policy interventions such as randomized vehicle searches.

The diversion we measure is driven by individual consumers engaging in cross-border shopping, as opposed to larger-scale activity driven by firms within the industry. Indeed, our data come from a system designed to track all activity in the marijuana industry to prevent diversion on the part of firms or industry employees. This cross-border activity is most similar to behaviors observed in tobacco and alcohol markets, where consumers cross borders chiefly to avoid taxes or high prices(Chernick & Merriman, 2013; Merriman, 2010; Harding, Leibtag & Lovenheim, 2012; Lovenheim, 2008; Shelley, Cantrell, Moon-Howard, Ramjohn & VanDevanter, 2007; LoPiccalo, 2016). However, due to the conflict of state and federal laws, it remains a form of drug trafficking at the federal level.

This behavior exists in the context of differential incentives for marijuana consumers relative to consumers of tobacco and alcohol. Black market marijuana may be available at a lower price. Medical marijuana has been available in Oregon since 1998, and hundreds of medical dispensaries were operating during the period between Washington's recreational market opening and Oregon's recreational market opening. Furthermore, Hao & Cowan (2017) finds marijuana possession arrests in counties close to Washington and Colorado (which opened a recreational market at roughly the same time) in the period between the ballot initiatives and when markets first opened in 2014. This suggests law enforcement worked to minimize marijuana spill-overs in the years prior to the market openings in Colorado and Washington.

Our findings also contribute to the knowledge surrounding supply side interventions in illegal and quasi-legal drug markets, given that marijuana remains illegal at the federal level and in most states. Gavrilova, Kamada & Zoutman (2014) find evidence medical marijuana

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laws reduced illegal trafficking of the substance, and the related flow of marijuana between Mexico and the United States. In contrast, we estimate the impact on recreational markets on the flow of marijuana within the United States. Evidence suggests supply side interventions aimed at reducing the supply of methamphetamine have had limited and merely short-term success (Dobkin & Nicosia, 2009; Dobkin, Nicosia & Weinberg, 2014). We discuss possible interventions in this market in Section 4.

In Section 2, we provide context on marijuana's legalization in Washington and Oregon. In Section 3 we discuss Washington's administrative data on recreational marijuana sales and our methodology. In Section 4 we present our main estimates, several placebo analyses, and additional analyses aimed to address potential mechanisms. Finally we conclude and discuss the implications of our findings for current policy debates.

2   Background

Prior to 1938, marijuana was legal in the United States. Indeed, it was listed in the United States Pharmacopeia as an effective treatment for labor pains, nausea, and other conditions. Since the passage of the Marijuana Taxation Act of 1938, the consumption of marijuana has been illegal throughout the United States, though many states had previously banned the substance, including Washington and Oregon in 1923 and Idaho in 1927 (Sanna, 2014, p. 88). The advent of Scheduled substances in the Controlled Substances Act of 1970 significantly strengthened the prohibition against marijuana, as it was quickly classified a Schedule I substance with a 'high potential for abuse and little known medical benefit.'[6]

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[6]Other Schedule I substances include heroin and methamphetamine.

Throughout the past century, public attitudes toward marijuana have shifted, particularly for medical use. In 1973, Oregon became the first state to decriminalize the possession of small amounts of marijuana, though cultivation and distribution remained a felony. A number of subsequent ballot initiatives and legislative efforts in a number of states culminated in a successful 1996 effort in California to legalize marijuana for medical use. Oregon and Washington followed via separate ballot initiatives in 1998. Currently, 27 states and regions permit the cultivation and use of marijuana for medical reasons.

Initially, federal prosecutors continued to enforce the Controlled Substances Act in states with medical marijuana laws. These efforts culminated in *Gonzales v. Raich* 545 U.S. 1 (2005), a U.S. Supreme Court case stemming from a 2002 enforcement action that destroyed marijuana plants owned by Californian medical licensees. The patients sued the government, claiming, in part, that since the marijuana had been produced and used entirely within California's borders, interstate commerce was unaffected and therefore Congress had no power to regulate via the Commerce Clause of the U.S. Constitution. In it's 6-3 opinion, the Supreme Court sided with the government, in part due to the "difficulties that attend distinguishing between marijuana cultivated locally and marijuana grown elsewhere ... and concerns about diversion into illicit channels."

However, as the number of states with medical marijuana laws grew, and public opinion shifted, federal enforcement policy adjusted as well. In October 2009, the Department of Justice issued a memorandum discussing the allocation of resources in states with medical marijuana laws. The memo specified that "federal resources in [legal] States" should not be focused "on individuals whose actions are in clear and unambiguous compliance with existing state [medical marijuana] laws." though the memo also emphasized a need to investigate and

prosecute "drug traffickers who hide behind claims of compliance with state law" (Ogden, 2009, p.2). This has been broadly interpreted as an effort to defer to states' choices in the absence of federal consensus (Stout & Moore, 2009).

In the election of November 2012, Washington voters approved Initiative 502, which legalized the production, sale, possession, and consumption of marijuana for recreational purposes for adults over 21. Colorado passed a similar ballot measure, making these two states the first with recreational marijuana markets. The law created a three-tiered regulatory system, with separate licenses for cultivators (legally 'producers'), who are permitted to grow cannabis plants; another for processors, who transform harvested plant material into usable marijuana and other products for wholesale distribution; and a third for retailers, who may sell the final products to consumers.[7]

In August 2013, during the implementation of Initiative 502, the Department of Justice responded to the Washington and Colorado efforts with a memo written by James Cole, then the Deputy Attorney General (Cole 2013). The "Cole Memo" emphasized the prohibition and consumption of marijuana under federal law but provided guidance to U.S. Attorneys as to specific enforcement priorities. One federal priority was "preventing the diversion of marijuana from states where it is legal under state law in some form to other states." Others included preventing consumption by minors, preventing revenue from marijuana sales from going to "criminal enterprises, gangs, and cartels," and "preventing drugged driving and the exacerbation of other adverse public health consequences associated with marijuana use." Importantly, the Department established a clear expectation that "states and local

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[7]Initiative 502 set up a number of vertical integration and ownership constraints for firms that do not bear upon this analysis. Additionally, the Initiative specified a tax structure that was later reformed extensively before Oregon's market opened. These details, particularly the tax system and later reformed, are studied by Hansen, Miller & Weber (2017).

governments... will implement strong and effective regulatory and enforcement mechanisms."

To comply with the enforcement priorities laid out in the Cole Memo, Washington implemented a "traceability" system to track the cultivation, testing, processing, and retail sales of marijuana. At every step, the system tracks each gram of marijuana produced and each dollar transferred. The data is verified through random site audits backed by penalties ranging from fines to inventory destruction and loss of license. In this way, Washington's system is designed to ensure that marijuana is not diverted from within the supply chain to black markets. We provide more details on the administrative data gathered from this system in Section 3. After the traceability system was implemented, Washington's recreational marijuana market began on July 8, 2014.

The Cole Memo had a marked effect on subsequent legalization efforts. Indeed, when proponents of legalization in Oregon filed ballot Measure 91 in 2014, the text specified a specific intent to comply with each priority specified by the Cole Memo using the Memo's precise language. Voters approved the measure in the November 2014 elections.

Though the Oregon measure formally legalized the possession and use of marijuana for recreational purposes on July 1, 2015, retail stores were not expected to open until late 2016. In July, 2015, Oregon's Governor signed a bill allowing existing medical dispensary locations to sell recreational marijuana starting October 1, 2015, citing the need to curb black market usage and hasten the transition to a revenue-producing legal market (Sebens, 2015). While Oregon developed a seed-to-sale tracking system comparable to Washington's system, it was not implemented when markets opened in October. As such, we cannot observe details of Oregon's retail market at the time of its opening, as we can with Washington.

3   Data and Methods

Our data consist of administrative records from the "traceability" system maintained by the Washington State Liquor and Cannabis Board (WSLCB). The system was designed to track each step in the marijuana supply chain, enabling state officials to collect taxes and enforce regulations. To ensure accurate data, WSLCB employees conduct random in-person audits. Violators face penalties that include inventory seizure and destruction. The end result is data that tracks the planting, harvest, and production of cannabis plants into usable goods, the sale of those goods to a retailer, and final retail sale of marijuana products. Along the way, products are tested for potency via the concentration the primary psychoactive components in marijuana, including tetrahydrocannabinol (THC).

We utilize an extract of the state's database that includes all plants and products. Firms and locations are given unique identifiers. Each plant is registered at the time of planting. Firms record the provenance of the plant material (e.g., a clone or a seed) as well as the strain (analogous to a cultivar). Once harvested, flowers and other plant material are collected and converted into a new "inventory lot" that is assigned a unique identifier (ID); products or material within a single inventory lot are assumed to be homogeneous.

The last processing step is the division of a large wholesale inventory lot into multiple smaller lots for sale to individual retail stores. Each retail lot consists of multiple sealed packages of a specific weight of marijuana (e.g. 1 gram or 2 grams) which are considered identical. When lots are sold to retailers, the tracking system records the date, quantity, and price of the transaction and assigns a new lot ID. Consequently, the observation of a retail lot ID uniquely identifies the retailer, processor, and cultivator, as well as the strain

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and package size. The system tracks individual retail sales, linking the prices and quantity of different items, as well as the transaction time,[8] in a given sale to the relevant lots.

As retail firms are generally excluded from financial services markets, almost all firms choose to set tax-exclusive prices in such a way that when the marijuana-specific excise tax and Washington's general and locality-specific sales taxes are included, consumers pay a round number. This lowers the cash handling costs for firms, and in contrast to other settings, implies that sales taxes are salient to consumer-level decision making. We therefore conduct analyses based on tax-inclusive prices and clean the price data as needed.

We analyze the effects of Oregon's recreational market opening on a number of observable behaviors of market participants through a series of regression exercises. We restrict our analysis at the processor and retail levels to the "usable marijuana" product category—74.5% of the total transactions observed in our data.[9] For each component of the supply chain—cultivators, processors, and retailers—we collapse the data by firm-day, unless otherwise specified. We perform minor cleaning steps and exclude firms for which we do not have at least one month of data on either side of the reform. None of this cleaning significantly changes our results. We provide additional details in the Online Data Cleaning Appendix.[10]

Because the reform took place within the broader context of the market's non-linear evolution, our estimating equations include a polynomial in time. We include dummy variables for the days immediately surrounding the reform, to account for short-term adjustment effects. We also include dummies for the days surrounding Labor Day and Thanksgiving

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[8]Washington does not require retailers to have a constant connection to the tracking system. Many connect to the system at the end of their business day and upload their transactions within one session. To ensure consistency across firms, we choose the daily level as our most granular view of industry activity.

[9]We have examined the 'edible' and 'concentrate' categories, which have higher heterogeneity. The point estimates are qualitatively similar, but the results are noisier and are difficult to interpret.

[10]Data cleaning appendix available at http://www.keatonmiller.org/s/data-cleaning-appendix.pdf

holidays. We analyze behaviors at the firm-day level, though cyclical patterns at the weekly and monthly levels lead us to include additional fixed effects. Our window of analysis spans the two months before and two months after the reform.

Our analyses, therefore, use the following template:

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\begin{aligned}
log(y_{it}) =& \alpha_0 + \alpha_1 ORmktopen_{it} + \sum_{j=1}^{15} \alpha_{3j} ORmktopen\_day_j + \sum_{k=1}^{6} \alpha_{3k} dow_k \\
& + \sum_{l=1}^{31} \alpha_{4l} dom_l + \sum_{m=1}^{5} \alpha_{5m} date_t^m + \sum_{c=1}^{C} \sum_{m=1}^{5} \alpha_{5cm} date_t^m \cdot county_c + \alpha_6 X_{it} \qquad (1) \\
& + \alpha_{7i} + u_{it}.
\end{aligned}
$$

where y_{it} is the log of outcome variable for firm i at date t, $ORmktopen_{it}$ is an indicator variable for Oregon's market opening that is one after October 1, 2015 and zero before, $ORmktopen\_day_j$ are indicator variables for September 30 - October 2, September 6 - September 11, and November 24 - 29 to absorb local responses to the market opening in Oregon, the days surrounding Labor Day, and the weekend of Thanksgiving, dow_j are day of the week fixed effects, dom_k are day of the month fixed effects, $date_t^m$ is a polynomial in the date of sale, $date_t^m \cdot county_c$ are county-specific date polynomials to allow for county-specific time trends, X_{it} are covariates including the log wholesale price of goods sold that day, the log of average competitor's price within 10 miles, and an indicator for whether there are any competitors within 10 miles. Firm fixed effects are captured by α_{7i}. We cluster standard errors by retail firm, as opposed to retail location.[11] We show that our estimates are very robust to plausible alternative specifications in Section 4.2.

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[11]These standard errors are more conservative than either clustering by date or a two-way cluster on date and retail firm. They are also marginally more conservative than clustering by retail location.

Our estimating equations implement a regression discontinuity design, where time is the running variable which determines if firms are exposed to treatment.[12] Recently, Hausman & Rapson (2017) formalized some of the differences between time-based regression discontinuity applications, which are similar to event studies, and other uses of the regression discontinuity framework. For instance, since our data are panel data, testing for covariate balance (Hahn, Todd & Van der Klaauw, 2001) or running variable smoothness (McCrary, 2008), is unnecessary as these features are guaranteed by the panel nature of the data.

The distance between between Oregon's population centers and Washington's border counties provides insight into where individuals from Oregon might reasonably travel in the pursuit of legal marijuana. Table 1 reports, for each Washington county, the closest distance between one of its retailers and the center-of-population for those Oregon counties for which the Washington county has the closest retailer.[13] Table 1 also reports the sizes of each county in question. Chiefly, Clark and Klickitat counties in Washington contain retailers which are the closest point of sale for majority of Oregon's population.

Table 2 provides summary statistics for groups of Washington counties based on their border status. We report summary statistics for three periods: the two months before Oregon formally legalized the possession and use of marijuana for recreation on July 1, 2015, the two months before Oregon's market opened on October 1, 2015, and the two

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[12]Regression discontinuities with time as the running variable have been used in a wide variety of other contexts including the mass releases of prisoners (Buonanno & Raphael, 2013), state-level court decisions (Grainger, 2010), and DNA testing (Doleac, 2017).

[13]Though Skamania County borders Oregon, the regional geography means that the center-of-population of each of Oregon's counties is closer to a retailer in some different county, though some towns in Oregon's Multnomah and Hood River Counties are closest to the retailer in Skamania County. Additionally, firms did not open in Walla Walla County until either the day before or well after October 1, so the closest firms to Wallowa county in the sample we consider are actually in Whitman county (which does not actually border Oregon), which we consider an Idaho border county for this analysis. We are not concerned about this as Wallowa county is very small (7,008 people) and fairly far away from Whitman county. If anything, it makes it more likely that our placebo test described below will be violated.

months after Oregon's market opened. Though the quantity of marijuana sold in Washington increases between July and October, the increase is proportional across all four sets of counties, indicating the legalization date did not have a strong effect on Washington's market. In contrast, there is a significant decline in the weight sold in the Oregon border counties around Oregon's market opening. The overall share of Washington's market, by weight, declined from 10.2 percent to 7.2 percent. The entries for Idaho counties suggests significant diversion may be happening there as well – though those counties only hold 7.7 percent of Washington's population, their retailers hold 18 percent of the market share.

4   Results

We begin by presenting our primary results and follow with heterogeneity analysis in Section 4.1 that provides evidence that the effect we find is diversion behavior, not drug tourism. Section 4.2 examines the robustness of our findings and Section 4.3 considers other outcomes that could be influenced by the opening of Oregon's recreational marijuana market beyond the weight of marijuana sold.

Given the dispersion in retail locations, our primary analysis considers border counties as a natural starting point. There are 18 retail firms (19 locations) across the six Oregon border counties that have at least one retailer. Table 3 Column (1) estimates the change in total weight per retail location-day for these locations in response to the opening of Oregon's recreational marijuana market using equation (1). We find a 41.4 percent decrease (significant at the 0.1 percent level) in marijuana demand in Washington counties that border Oregon in response to the opening of Oregon's recreational marijuana market. Per Table 2,

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Oregon border counties sold 286 kilograms of marijuana per month before Oregon's market opened, so this implies the weight sold along the border dropped by 118 kilograms per month.

The top panel of Figure 1 illustrates this change by plotting the raw data. The fitted line in the figures plots a fifth-order polynomial through the raw data (allowing for a jump when Oregon's market opened), while controlling for only cyclical trends (day-of-month and day-of-week effects). The hollow circles plot the raw data with the cyclical trends removed. Figure 1 suggests that there was no anticipatory response on the part of consumers and it took consumers two days after the reform to fully adjust their purchasing behavior.[14]

Washington is bordered by Oregon, Idaho, and Canada, which gives us two placebo tests for our analysis – the Idaho and Canadian borders – which experienced no related policy changes on October 1. We present these estimates in Columns (2) and (3) of Table 3 and the bottom panels of Figure 1. Both the table and figure highlight no response at either of these other borders.[15]

In Column (4) of Table 3, we pool the three borders and estimate the response at each border separately; so, if we wanted to estimate a differences-in-RD design, we could subtract the estimate from Idaho or Canada (or the average of the two) from the Oregon estimate. This is similar to a recent approach from Grembi, Nannicini & Troiano (2011) and other advances in doubly-robust estimation (Kline, 2011). The results are very similar to our baseline estimates. Column (5) estimates a naive difference-in-differences design. We estimate the effect at the Oregon border relative to the effect at the Idaho and Canadian borders ignoring our ability to control for the distance in time from October 1 ; that is, we exclude the

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[14]This period corresponds with the first Saturday following Oregon's legal market opening, which anecdotally was the grand opening announced by several firms on social media.

[15]We present analogous placebo tests for other outcomes we examine in Appendix A.

county-specific polynomials in date of sale from this regression. This matters: the estimate drops by about 20 percent in Column (5), but is still significant at the one percent level. This highlights the value of having daily data, which allows us to separately control for the nonlinear evolution of demand in each border county in our primary specification.

Table 4 and Figure 2 examine the response at the Oregon-Washington border by distance. If substantial diversion to Oregon was occurring before Oregon's market opened, the set of retailers closest to the Oregon border should be those most affected by the change, all other things equal. Indeed, we find that the decrease in weight is concentrated within the first 25 miles from the Oregon border – the effect here is approximately the same as we found for border counties. The effect drops by half for those retailers in the next 25-mile zone of distance from the Oregon border, and by half again thereafter.

Following the "gradient" approach to studying border effects (Lovenheim, 2008), Column (5) of Table 4 estimates the quantity of marijuana sold by firms as a function of the log distance of firms from the Oregon border. We remove the sales location fixed effects in this specification, but add county-level population and income from the 2010 Census so that we can accurately capture the gradient both before and after Oregon's market opened.

The gradient before Oregon's market opening (i.e. the coefficient on log distance) is significant at the five percent level, which implies either Washingtonians near the Oregon border have high demand conditional on population and income and this demand decreases away from the border, or there are a large volume of purchases by Oregonians in neighboring Washington counties before Oregon's market opened. This gradient dissipates after Oregon opens its market, as evidenced by the sum of the coefficients on log distance and the interaction between this variable and an indicator for the period after Oregon's market opens – the

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combined effect of distance is about half as large after the market opening and is no longer significantly different from zero. This lends support to the second hypothesis.

The coefficient on Oregon's market opening indicator suggests that the quantity sold right at the border drops by over 60 percent, but this large response dissipates with distance. The rate of dissipation is plotted in the left panel of Figure 2. Within 100 miles, the decrease in weight loses statistical significance. We explore the fit of this specification in the right panel of Figure 2, which plots the estimated response to the market opening separately for each firm and then fits a quadratic line through the individual firm estimates. It appears that while the general shape is consistent with the parametric model of the gradient, the starting point is too low relative to what the actual data suggest. Of the retail locations within 25 miles to the border, 53.3 percent are statistically significant at the five percent level, whereas between 25 and 100 miles, only 3.8 percent are statistically significant. We repeat this analysis on the Canadian and Idaho borders in Appendix A.

4.1 Diversion, Reverse Diversion, and Tourism

The results presented so far provide compelling evidence that Oregonians are purchasing substantial quantities of marijuana from Washington prior to Oregon's market opening. Since there are no systematic inspections at the Oregon-Washington border, it is completely plausible that Oregon residents are diverting marijuana by bringing it back to Oregon. However, it could also be that Oregonians are participating in drug tourism by traveling to a Washington border county and consuming marijuana while there.[16] Reverse diversion – Washingtonians

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[16]Anecdotal evidence suggests that the marijuana tourism industry in Washington is small and concentrated in Seattle (King County) and Spokane (Spokane County), rather than along the Oregon border. The website `Kushtourism.com` provides information to those interested in marijuana tourism in Wash-

traveling to Oregon to purchase marijuana at a lower price – is also a potential concern.

We explore these competing explanations by examining heterogeneity in the response along multiple dimensions. Figure 3 splits retail transactions by size. All transactions under a gram are the group captured by the left-most point estimate – given by a round dot (95 percent confidence intervals are given by the thin lines). We plot the coefficient for one gram sales (up to the 25th percentile), one to two grams (25th to 50th percentile), two to 3.5 grams (50th to 75th percentiles), 3.5 to six grams (75th to 90th percentiles), and greater than six grams (above 90th percentile).[17] The effect is concentrated in the largest transactions, which is suggestive that, before Oregon's market opened, individuals were purchasing substantial amounts of marijuana, consistent with bringing marijuana back to Oregon.

Table 5 explores additional heterogeneity specifications. As tourism is typically higher on weekends than weekdays, Column (1) examines whether the observed decrease in quantity sold is different on weekdays or weekends. We find no significantly different effect for weekend days, consistent with diversion and inconsistent with tourism. Likewise, the reduction we observe is during the fall, a time period outside the typical peak tourism season regionally.

If the drop in sales was associated with drug tourism, we might expect that drop to be correlated with pre-existing tourism in the region. Table 5 Column (2) estimates the weight response separately for each Oregon border county. Interactions are relative to Clark County (where Vancouver, WA is located across from Portland, OR). We find the largest declines

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ington, Colorado, and other legal markets. Only one location is recommended along the border – most listings are for the Seattle region. Furthermore, the Washington marijuana tourism industry has lagged Colorado's significantly. Other coverage in the media has suggested this could be due to more stringent indoor smoking bans, and points out there are three marijuana tours in Seattle related to marijuana while 10 similar tours are offered in Denver. See `http://www.thestranger.com/news/2016/06/22/24238128/why-seattle-is-failing-at-pot-tourism`.

[17]The percentiles are calculated for all Washington counties along the Washington-Oregon, Washington-Idaho, and Washington-Canada borders in the two months preceding Oregon's market opening.

occur in Clark and Klickitat counties. These two counties are the closest destinations for the largest shares of the Oregon population as shown in Table 1, though they differ substantially in size: Clark is the largest border county (population: 425,363) and Klickitat is one of the smallest (population: 20,318). They are also very different in tourism. Of the border counties, Clark County receives the highest spending, with $364 million recorded in 2009 (i.e. before Washington legalized marijuana for recreational use), and Klickitat the lowest, with $32 million (Washington State Department of Commerce, 2010).

Cowlitz and Skamania Counties experience significantly smaller effects than Clark County, which is not surprising as the Skamania retailer isn't the closest destination for any Oregon counties and Cowlitz is the closest destination for only one county. Benton and Pacific also experience smaller declines than Clark County; Benton County is closest to the third largest share of Oregon counties and Pacific is closest to just one Oregon county.

Table 5 Column (3) examines King County, which includes Seattle. Arguably, Seattle and the surrounding area should experience the largest volume of drug tourism, as it is the hub of the state (including the major airport in Washington). We find an effect of approximately zero in King county (and the 95 percent confidence interval for this estimate does not overlap with that of our baseline estimate for Oregon border counties).

Taken together, this evidence suggests that the county-level characteristic that matters the most is distance to Oregon's population, rather than pre-existing tourism activity. This supports the notion that the effect we capture is driven by diversion behavior.

Finally, reverse diversion might have occurred if Washingtonians, who faced a 37% tax on marijuana in their own state, crossed the border to Oregon, who faced no taxes on marijuana for the first few months after the market opened. Though administrative data on prices

were not collected in Oregon at the time of the opening and Colorado data are unavailable, evidence from Washington's data and anecdotal reports from Oregon and Colorado suggest that recreational markets in all three states began with prices that surged higher than medical and black markets until recreational supply increased to compensate for excessive demand. This would serve to minimize inter-state border shopping to evade taxes. We test this hypothesis in Appendix B by examining the response in Washington to the introduction of a 25% retail excise tax in Oregon in January 2016 – which, if reverse diversion was occurring, would reduce its extent and increase the weight sold in Washington. We find no change.

4.2   Robustness

Table 6 and Figure 4 provide evidence that our preferred estimates are robust to a large variety of specifications. We repeat this analysis on the other borders in Appendix A. Table 6 repeats our baseline estimate of the change in total weight demanded, on average, from a Washington retailer in an Oregon border county in response to Oregon's market opening.

Table 6 Columns (2) and (3) consider variations in the local adjustment window around the opening of Oregon's market. Column (2) eliminates the local adjustment window. The estimates decline by about 20 percent, which is not surprising given that there appears to have been a short adjustment period, particularly on October 1 and 2. Column (3) extends our adjustment window by an additional day on either side of October 1. This leaves the estimates approximately unchanged, suggesting that our baseline specification fully captures the local adjustment. Column (4) drops our indicator variables around holidays. This has little effect, likely because these holidays are distant from October 1. Column (5) adds firm-

specific weekend effects, by adding indicators for Friday, Saturday, and Sunday interacted with each retail location. We consider this because firms variably choose which days to open and weekend effects potentially vary by location; the inclusion of these variables has almost no effect. Column (6) drops the controls for own and competitors' wholesale prices and whether or not there are any competitors which increases the estimates and standard errors slightly. Column (7) adds the number of competitors, which changes as new firms enter the market or old firms exit. This doesn't change the results. Column (8) drops the county-specific polynomials from the regression. The estimates increase by about 20 percent and the standard errors increase by about 60 percent. While our estimates remains statistically significant even without the county-specific trends, the additional precision they offer merits their inclusion in our preferred specification.

Figure 4 examines the sensitivity of our estimates to bandwidth and polynomial choice. The left panel varies the number of weeks included in our analysis from six to 11 weeks. Our estimates are very insensitive to our choice of bandwidth. The right panel considers different polynomial choices: linear, linear interacted with an indicator for the opening of Oregon's recreational marijuana market, quadratic, cubic, and quintic. Our estimates are highly robust to our choice of polynomial.[18]

4.3 Other Outcomes

Up to this point, we have only considered the weight of marijuana demanded by consumers from retail locations as a potential response to the opening of Oregon's recreational marijuana

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[18]We cannot construct the optimal bandwidth in the style of Calonico, Cattaneo & Titiunik (2014) because of our day-of-week and day-of-month fixed effects (necessary due to strong cyclical patterns in the data) lead to a high degree of multicollinearity. However, if we use their approach to choose the optimal polynomial it leads to a negligible bias adjustment to our point estimate and a p-value of 0.004.

market. This section examines potential responses along other dimensions, such as prices, sales, revenue, inventory, and THC concentration.

Table 7 Column (1) repeats our baseline weight estimates for reference. We might imagine that prices would change in response to this large shock in the demand for marijuana, but Column (2) finds no such effect on the tax-inclusive price of marijuana sold. Given the large decrease in sales apparent after legalization, this suggests the supply of marijuana is quite elastic.[19] Processors cannot adjust the amount of marijuana grown overnight (most are vertically integrated with a cultivator), but this suggests they are quite able and willing to adjust the amount sold at a particular time for a given price. This is likely driven in part by Washington's regulations, which stipulate that products must be sold in sealed containers, giving them a long shelf life. Columns (3) and (4) find tax-inclusive revenue and sales fall by slightly lower amounts. Column (5) finds that inventory rises substantially (although the estimate is not significant), which suggests retailers were taken by surprise, at least in the short-run, by the decline in demand following Oregon's market opening.

4.4 Policy Implications

The chief policy question motivating this article is the extent to which marijuana produced within a state's legal, regulated system is ultimately diverted to other states. We estimate this amount by applying our estimated response in Table 3 to the quantities of usable marijuana sold in Washington's border counties with Idaho and Oregon in the two months before

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[19]In Hansen et al. (2017), we highlight that these estimates can include compositional changes and consider inventory lot-day level estimates as an alternative that holds these compositional changes constant. We find similar qualitative results.

and after Oregon's market opened, as reported in Table 2.[20] Figure 5 illustrates the results.

We estimate that 41.4% of the marijuana sold in border counties was diverted. In the two months leading up to Oregon's market opening, therefore, we estimate that 237 kilograms of usable marijuana was diverted from Washington to Oregon and 433 kilograms was diverted from Washington to Idaho. In the two months after, assuming Oregon consumers switched to in-state retailers, 444 kilograms was diverted from Washington to Idaho.

Figure 5 illustrates these quantities as a fraction of the total weight sold in Washington for these two-month periods. Notably, the quantity diverted to Idaho is estimated to be much higher than the quantity diverted to Oregon before Oregon's market opened. This is not surprising, given the outsized share of the state market held by retailers in Idaho border counties, as seen in Table 2.[21]

Given this degree of diversion, it is natural to ask how preventable this behavior may be. The Oregon Department of Transportation estimates that 293,840 vehicles per day traveled between Oregon and Washington in Clark and Klickitat counties in 2015.[22] In the months prior to Oregon's market opening, an average of 1,662 retail transactions occurred in these counties per day. Given our estimates, a policy of randomly searching border-crossing vehicles could expect to find diverted recreational marijuana in just 0.47 percent of stops.

The Idaho and Washington Departments of Transportation estimate that 107,311 vehicles crossed the border in Spokane and Whitman counties daily.[23] On average, there were 5,249

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[20]We ignore the possibility of diversion across the Canadian border as the international border crossing comes with some inspection of every vehicle and therefore the cost and risk of diversion behavior is likely much higher than diversion to Oregon or Idaho.

[21]Both Spokane and Whitman counties have state colleges in them. Because these college students are not generally included in the Census, we could be understating the population share along the Idaho border. However, this effect is small; adding the student populations of Washington State and Eastern Washington increases the population share along the Idaho border from 7.7 percent to 8.6 percent.

[22]http://www.oregon.gov/ODOT/Data/Pages/Traffic-Counting.aspx

[23]Data from http://www.wsdot.wa.gov/mapsdata/travel/annualtrafficreport.htm, and

sales per day in those counties in the two months prior to Oregon's market opening, which in turn would imply that police would expect a yield of 4.0 percent in randomized border stops. These estimated hit rates would be proportionally smaller if individuals make multiple stops when purchasing marijuana for diversion back to Oregon.[24]. Given Knowles, Persico & Todd (2001) police road-stops find drugs in roughly 30-40 percent of stops, the additional potential hit rate offered by randomized audits to drug diversion is minimal.

5 Conclusion

As recreational and medical marijuana markets continue to expand within the United States and globally – Canada, Columbia, the Netherlands, Spain, South Africa, and Uruguay have legalized marijuana for recreational use in some form, though not all have operating markets – the diversion of marijuana to jurisdictions where it remains illegal continues to be a public policy priority regardless of political affiliation. States have been advised to adopt seed-to-sale tracking systems to prevent diversion at the wholesale level, yet diversion through the mechanism of cross-border shopping by consumers has been largely undeterred.

We measure the extent of this consumer-level diversion by examining the demand for marijuana in Washington counties that border Oregon. In the days immediately following Oregon's market opening, the quantity of marijuana demanded in Washington's border counties fell by 41%. We find similar results whether we use a regression discontinuity approach

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http://itd.idaho.gov/road-data/. These may be under estimates, because while the Oregon/Washington border requires a select few bridges, the Washington/Idaho border has smaller access roads in addition to the major highways and freeways reported average daily traffic counts.

[24]As marijuana possession for amounts less than 3 ounces is a misdemeanor in Idaho based on code 37-2701, the legal code would serve to deter purchasing the multiple amount at more than 3 retailers in Washington

or a difference-in-differences approach with Idaho and Canadian border counties as placebos. Finally, estimates driven by both the time discontinuity and the geographic placebo produce nearly identical estimates, in the spirit of recent advances in doubly-robust estimation.

The magnitude of the spill-over effects on Washington's recreational sales in Oregon might be surprising given the relatively broad acceptance of marijuana in Oregon. Medical marijuana has been available in Oregon since 1998, and hundreds of licensed medical dispensaries opened between 2013 and 2015 prior to the opening of the first recreational stores. Furthermore, private citizens could grow up to 4 marijuana plants following the demand side legalization for private use in December of 2014. Despite readily available quasi-legal substitutes, sales in Washington border counties fell sharply and quickly following the opening of Oregon's recreational marijuana market – and did not fall earlier.

Though our evidence suggests a significant quantity of marijuana is diverted across state boundaries by inter-state shoppers, these results do not necessarily support proposals for the federal government to crackdown on recreational marijuana markets. First and foremost, a small minority of marijuana is actually diverted outside of the state. 5,624 kilograms of marijuana were sold in Washington in the two months prior to the opening of Oregon's recreational marijuana market, and 670 kilograms, or 11.9 percent were diverted across state lines. We find no evidence of declines throughout the rest of the state, implying only 7.5 percent of marijuana is diverted out of the state today.

Furthermore, traditional police investigations have prevented more marijuana diversion by uncovering illegal growing operations within Washington and Colorado (at a presumably low cost) than could be prevented by stopping all traffic at state borders (at a presumably high cost). For instance, police recently seized 1,814 kilograms and 2,500 plants for an illegal

grow operation in Colorado[25] and 3,000 plants (capable of yielding thousands of kilograms) in a Washington sting[26]. In both cases, the quantities seized are similar in magnitude to the amount of diversion we estimate over a period of many months.

Absent substantial and expensive efforts to inspect state border crossings, preventing diversion through individual transactions is likely to face significant barriers. Tracking individual purchases across retailers might help to prevent bulk purchases intended for resale, but limiting individual transactions of methamphetamine precursors only had temporary effects on the methamphetamine supply (Dobkin & Nicosia, 2009; Dobkin et al., 2014). Lastly, the inter-state diversion of recreational marijuana produced in legal markets may be preferred in a social welfare sense to drug trafficking through illegal markets (Conlin, Dickert-Conlin & Pepper, 2005; Adda, McConnell & Rasul, 2014; Gavrilova et al., 2014) – particularly if the inter-state shopping behavior results in additional tax revenue which is then used to offset the negative externalities of marijuana consumption (Marie & Zölitz, 2017).

The extent to which demand for marijuana falls in rural Washington counties, which lie a significant distance from relevant Oregon population centers, suggests consumers are revealing their preference for legal recreational products relative to black market products. This could be due to the variety of products offered, the presence of safety regulations, the additional product attribute information stemming from THC and CBD testing, and user reviews of products and retailers through Leafly and other services.

Our findings also suggest the western United States may experience minimal diversion relative to the rest of the country. Though the opening of retail outlets in California will

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[25]http://www.9news.com/news/crime/74-indictments-in-operation-toker-poker-ag-says-its-largest-pot-bu: 452759108
[26]https://patch.com/washington/seattle/3-000-pot-plants-seized-big-puget-sound-drug-bust-seattle-pol:

more than double the U.S. population with access to legal marijuana in their home state, and presumably provide a similar increase in the supply of marijuana grown in the U.S., California is surrounded by states where marijuana is legal – for recreational use on 81 percent of its borders (Oregon and Nevada), and for medical use on the remaining 19 percent (Holmes, 1998). On the other hand, significant diversion might be more likely in Massachusetts given it shares borders with 5 states, none of which have legalized recreational marijuana.[27]

Diversion at the retail level will likely remain a natural by-product of geographically heterogeneous policies restricting access, echoing similar behavior present in alcohol markets decades ago (Lovenheim & Slemrod, 2010) – though variation in health outcomes has not yet been documented. It remains to be seen the extent of diversion which could emerge as a result of heterogeneous tax rates and policies across states where it is legalized.(Merriman, 2010; Harding et al., 2012; Hansen et al., 2017) However, our results suggest one of the best ways for states to comply with the priorities specified by the Cole Memo is to be fortunate enough to have similarly-minded neighbors.

References

Adda, J., McConnell, B., & Rasul, I. (2014). Crime and the depenalization of cannabis possession: Evidence from a policing experiment. *Journal of Political Economy*, *122*(5), 1130–1202.

Bertrand, M. & Mullainathan, S. (2004). Are emily and greg more employable than lakisha and jamal? a field experiment on labor market discrimination. *The American Economic Review*, *94*(4), 991–1013.

Buonanno, P. & Raphael, S. (2013). Incarceration and incapacitation: Evidence from the 2006 Italian collective pardon. *The American Economic Review*, *103*(6), 2437–2465.

Calonico, S., Cattaneo, M. D., & Titiunik, R. (2014). Robust nonparametric confidence intervals for regression-discontinuity designs. *Econometrica*, *82*(6), 2295–2326.

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[27]While each of the states has legalized marijuana for medical use, the states on the east coast have restrictive medical supply with few dispensaries and a limited set of prescribable conditions.

Chernick, H. & Merriman, D. (2013). Using littered pack data to estimate cigarette tax avoidance in NYC. *National Tax Journal, 66*(3), 635.

Cole, J. M. (2013). Memorandum for all United States attorneys. `https://www.justice.gov/iso/opa/resources/3052013829132756857467.pdf`. Accessed: 2017-07-20.

Conlin, M., Dickert-Conlin, S., & Pepper, J. (2005). The effect of alcohol prohibition on illicit-drug-related crimes. *The Journal of Law and Economics, 48*(1), 215–234.

Dobkin, C. & Nicosia, N. (2009). The war on drugs: Methamphetamine, public health, and crime. *The American Economic Review, 99*(1), 324–349.

Dobkin, C., Nicosia, N., & Weinberg, M. (2014). Are supply-side drug control efforts effective? Evaluating OTC regulations targeting methamphetamine precursors. *Journal of Public Economics, 120*, 48–61.

Doleac, J. L. (2017). The effects of DNA databases on crime. *American Economic Journal: Applied Economics, 9*(1), 165–201.

Gavrilova, E., Kamada, T., & Zoutman, F. (2014). Is legal pot crippling Mexican drug trafficking organizations? The effect of medical marijuana laws on US crime. *The Economic Journal*.

Grainger, C. A. (2010). Redistricting and polarization: Who draws the lines in California? *The Journal of Law and Economics, 53*(3), 545–567.

Grembi, V., Nannicini, T., & Troiano, U. (2011). Do fiscal rules matter? A difference-in-discontinuities design.

Hahn, J., Todd, P., & Van der Klaauw, W. (2001). Identification and estimation of treatment effects with a regression-discontinuity design. *Econometrica, 69*(1), 201–209.

Hansen, B., Miller, K., & Weber, C. (2017). The taxation of recreational marijuana: Evidence from Washington state. Technical report, National Bureau of Economic Research.

Hao, Z. & Cowan, B. (2017). The cross-border spillover effects of recreational marijuana legalization. Technical report, National Bureau of Economic Research.

Harding, M., Leibtag, E., & Lovenheim, M. F. (2012). The heterogeneous geographic and socioeconomic incidence of cigarette taxes: Evidence from Nielsen homescan data. *American Economic Journal: Economic Policy, 4*(4), 169–198.

Hausman, C. & Rapson, D. S. (2017). Regression discontinuity in time: Considerations for empirical applications. Technical report, National Bureau of Economic Research.

Holmes, T. J. (1998). The effect of state policies on the location of manufacturing: Evidence from state borders. *Journal of Political Economy, 106*(4), 667–705.

Kline, P. (2011). Oaxaca-Blinder as a reweighting estimator. *The American Economic Review, 101*(3), 532–537.

Knowles, J., Persico, N., & Todd, P. (2001). Racial bias in motor vehicle searches: Theory and evidence. *Journal of Political Economy, 109*(1), 203–229.

LoPiccalo, K. (2016). Driving to drink: Tax avoidance along the Washington-Oregon border.

Lovenheim, M. F. (2008). How far to the border?: The extent and impact of cross-border casual cigarette smuggling. *National Tax Journal*, 7–33.

Lovenheim, M. F. & Slemrod, J. (2010). The fatal toll of driving to drink: The effect of minimum legal drinking age evasion on traffic fatalities. *Journal of Health Economics, 29*(1), 62–77.

Marie, O. & Zölitz, U. (2017). High achievers? Cannabis access and academic performance. *The Review of Economic Studies*, rdx020.

McCrary, J. (2008). Manipulation of the running variable in the regression discontinuity design: A density test. *Journal of econometrics, 142*(2), 698–714.

Merriman, D. (2010). The micro-geography of tax avoidance: Evidence from littered cigarette packs in Chicago. *American Economic Journal: Economic Policy, 2*(2), 61–84.

Meulbroek, L. K. (1992). An empirical analysis of illegal insider trading. *The Journal of Finance, 47*(5), 1661–1699.

Ogden, D. W. (2009). Memorandum for selected United States attorneys. `https://www.justice.gov/archives/opa/blog/memorandum-selected-united-state-attorneys-investigations-and-prosecutions-states`. Accessed: 2017-07-20.

Sanna, E. (2014). *Marijuana: Mind-Altering Weed*. Simon and Schuster.

Sebens, S. (2015). Oregon governor OKs early sales of recreational-use marijuana. *Reuters*.

Shelley, D., Cantrell, M. J., Moon-Howard, J., Ramjohn, D. Q., & VanDevanter, N. (2007). The $5 man: The underground economic response to a large cigarette tax increase in New York City. *American Journal of Public Health, 97*(8), 1483–1488.

Slemrod, J. & Weber, C. (2012). Evidence of the invisible: Toward a credibility revolution in the empirical analysis of tax evasion and the informal economy. *International Tax and Public Finance, 19*(1), 25–53.

Stout, D. & Moore, S. (2009). U.S. won't prosecute in states that allow medical marijuana. *The New York Times*.

Washington State Department of Commerce (2010). Washington state county travel impacts 1991-2009.

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6 Figures and Tables

Table 1: Washington Border Counties and Distance from Closest Retailer to Oregon Counties

WA County	Pop. (2010)	Retail locations	Oregon County	Pop. (2010)	Distance (Miles)
Benton	175,177	2			
			Baker	16,134	189
			Malheur	31,313	267
			Morrow	11,173	82
			Umatilla	75,889	78
			Union	25,748	149
			Total	**160,257**	**147**
Clark	425,363	6			
			Benton	85,579	90
			Clackamas	375,992	23
			Coos	63,043	242
			Curry	22,364	343
			Douglas	107,667	187
			Jackson	203,206	281
			Josephine	82,713	259
			Lane	351,715	122
			Lincoln	46,034	119
			Linn	116,672	88
			Marion	315,335	55
			Multnomah	735,334	12
			Polk	75,403	64
			Tillamook	25,250	82
			Washington	529,710	20
			Yamhill	99,193	43
			Total	**3,235,210**	**72**
Cowlitz	102,410	5			
			Columbia	49,351	29
Klickitat	20,318	3			
			Crook	20,978	120
			Deschutes	157,733	131
			Gilliam	1,871	68
			Grant	7,445	182
			Harney	7,422	267
			Hood River	22,346	10
			Jefferson	21,720	95
			Klamath	66,380	275
			Lake	7,895	280
			Sherman	1,765	29
			Wasco	25,213	13
			Wheeler	1,441	98
			Total	**342,209**	**153**
Pacific	20,920	2			
			Clatsop	37,039	55
Skamania	11,066	1			
			None		
Whitman	44,776	2			
			Wallowa	7,008	121

Pop. is population from the 2010 Census. Distance for Oregon counties is from the center of population in the county, as determined by the Census Bureau for 2010, to the nearest Washington dispensary calculated using the Open Source Routing Machine with Open Street Map data. Oregon counties are listed under the "nearest" Washington county; Skamania County in Washington is along the Columbia River portion of the Washington-Oregon border but its retail location is not the closest location to any of the centers-of-population of Oregon's counties. Distance for "Total" is from author-calculated weighted center of population for counties in panel to nearest Washington dispensary.

Table 2: Weight Sold and Population for Washington Border Counties

	Pre-OR Legal	Pre-OR Mkt. Open	Post-OR Mkt. Open
	Oregon Border Counties		
Total Population (in 2010)	558,446	558,446	558,446
Total Weight (in grams over two months)	380,834	572,398	425,989
Population Share	0.112	0.112	0.112
Market Share	0.113	0.102	0.072
Average Tax-Inclusive Price	$14.07	$13.42	$12.45
	Idaho Border Counties		
Total Population (in 2010)	381,487	381,487	381,487
Total Weight (in grams over two months)	609,986	1,046,517	1,073,976
Population Share	0.077	0.077	0.077
Market Share	0.177	0.186	0.181
Average Tax-Inclusive Price	$11.87	$11.91	$11.47
	Canadian Border Counties		
Total Population (in 2010)	272,683	272,683	272,683
Total Weight (in grams over two months)	194,371	305,098	303,953
Population Share	0.055	0.055	0.055
Market Share	0.056	0.054	0.051
Average Tax-Inclusive Price	$13.02	$12.13	$11.47
	Non-Border Counties		
Total Population (in 2010)	3,745,359	3,745,359	3,745,359
Total Weight (in grams over two months)	2,263,039	3,700,283	4,142,631
Population Share	0.755	0.755	0.755
Market Share	0.656	0.658	0.697
Average Tax-Inclusive Price	$13.67	$12.91	$12.55

Pre-OR Legal calculates each row over the two months before Oregon legalized marijuana (May and June 2015). Pre-OR Mkt. Open calculates each row over the two months before Oregon opened its recreational marijuana market (August and September 2015). Post-OR Mkt. Open calculates each row over the two months after Oregon opened its recreational marijuana market (October and November 2015). Total population is the total population in the counties specified from the 2010 Census. Total weight is the total weight (in grams) of marijuana sold over the relevant two month window for the counties specified. Population share divides the total population in those counties by the total population in the state of Washington. Market share divides the total weight in those counties by the total weight in Washington. The average tax-inclusive price is the average retail location price across the two-month interval.

Table 3: Retail Weight Response for Border Counties

	(1) OR Border	(2) ID Border	(3) CAN Border	(4) Combined	(5) DD
OR Border: OR Mkt. Opens	−0.414*** (0.081)			−0.444*** (0.076)	−0.331** (0.110)
ID Border: OR Mkt. Opens		−0.035 (0.028)		−0.041 (0.034)	
CAN Border: OR Mkt. Opens			−0.021 (0.072)	−0.013 (0.055)	
Counties Included:	OR Border	ID Border	CAN Border	All Borders	All Borders
Observations	2,272	2,039	1,838	6,149	6,149
R-squared	0.882	0.899	0.865	0.908	0.887
Retail Firms	18	17	16	51	51

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Table 4: Oregon Border Retail Weight Response by Distance

	(1) 0mi-25mi	(2) 25mi-50mi	(3) 50mi-75mi	(4) 75mi-100mi	(5) Gradient
OR Mkt. Opens	−0.439*** (0.084)	−0.158 (0.045)	−0.088 (0.084)	−0.077 (0.061)	−0.686*** (0.177)
OR Mkt. Opens x Log Distance to OR Border					0.103* (0.048)
Log Distance to OR Border					−0.249* (0.112)
Distance to OR Border Included:	0mi-25mi	25mi-50mi	50mi-75mi	75mi-100mi	0mi-100mi
Observations	1,814	365	1,040	1,666	4,885
R-squared	0.896	0.905	0.811	0.923	0.400
Retail Firms	14	3	9	14	40

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Table 5: Oregon Border Retail Weight Response Heterogeneity

	(1) Weekend	(2) Counties	(3) King County
OR Mkt.Opens	−0.406*** (0.077)	−0.582*** (0.111)	0.011 (0.034)
OR Mkt.Opens x Weekend	−0.019 (0.031)		
OR Mkt.Opens x Klickitat		0.087 (0.107)	
OR Mkt.Opens x Cowlitz		0.343* (0.124)	
OR Mkt.Opens x Skamania		0.540*** (0.114)	
OR Mkt.Opens x Benton		0.169 (0.323)	
OR Mkt.Opens x Pacific		0.174 (0.119)	
Counties Included:	OR Border	OR Border	King
Observations	2,272	2,272	4,186
R-squared	0.882	0.882	0.920
Retail Firms	18	18	35

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Table 6: Robustness Checks for Retail Weight Response in Oregon Border Counties

|	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Or Mkt. Opens	−0.414*** (0.081)	−0.321** (0.082)	−0.411*** (0.090)	−0.412*** (0.078)	−0.417*** (0.081)	−0.451*** (0.096)	−0.410*** (0.081)	−0.501** (0.130)
Indicators for Sept.30 and Oct. 2?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Indicators for Sept. 29 and Oct. 3?	No	No	Yes	No	No	No	No	No
Indicators for Holidays?	No	No	Yes	No	No	No	No	No
Weekend Days x Retail Location?	No	No	No	Yes	No	No	No	No
Processor Prices Included?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
# Competitors Included?	No	No	No	No	No	No	Yes	No
County x Polynomial Included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Observations	2,272	2,272	2,272	2,272	2,272	2,272	2,272	2,272
R-squared	0.882	0.881	0.882	0.875	0.888	0.875	0.882	0.839
Retail Firms	18	18	18	18	18	18	18	18

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions unless otherwise specified in the table above: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Table 7: Responses of Additional Variables at Oregon Border

|	(1) Weight	(2) TI Price	(3) TI Rev.	(4) Sales	(5) Inv.	(6) THC
OR Mkt. Opens	−0.414***	0.009	−0.389***	−0.335**	0.112	0.003
	(0.081)	(0.021)	(0.076)	(0.102)	(0.100)	(0.012)
Observations	2,272	2,272	2,272	2,272	2,272	2,272
R-squared	0.882	0.858	0.893	0.933	0.947	0.661
Retail Firms	18	18	18	18	18	18

The dependent variable is listed below the column number for each retail sales location-day. TI stands for tax-inclusive. Inv. stands for the inventory at the start of the day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

### Figure 1: Retail Weight Response for Border Counties
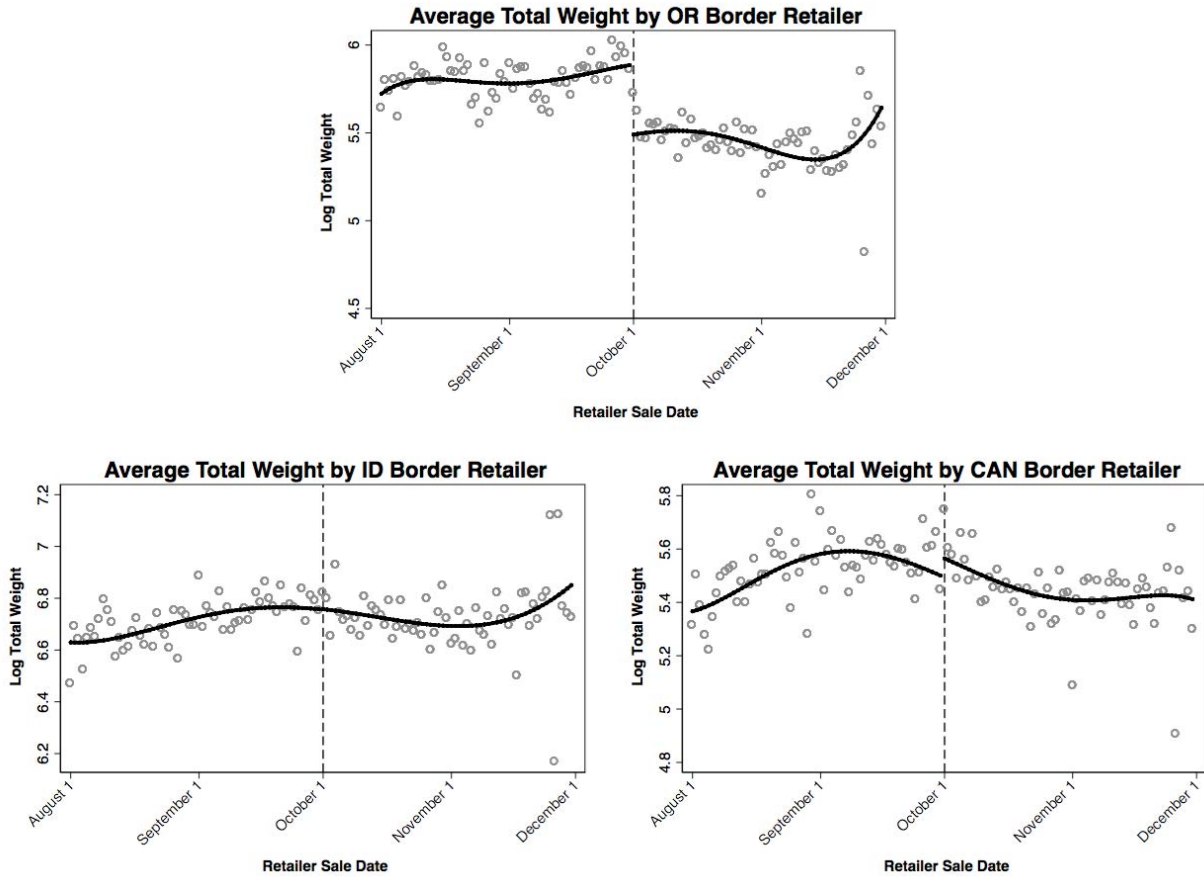
These figures illustrates the shifts in total weight per retail location surrounding the opening of Oregon's market that are estimated in Column (1) - (3) of Table 3 by plotting the raw data. The fitted line in the figures plots a fifth-order polynomial through the raw data (allowing for a jump when Oregon's market opened), while controlling for only cyclical trends (day-of-month and day-of-week effects). The hollow circles plot the raw data with the cyclical trends removed. The vertical dashed line marks the day Oregon began selling recreational marijuana, October 1, 2015.

**Figure 2: Retail Weight Response by Distance to the Oregon Border**
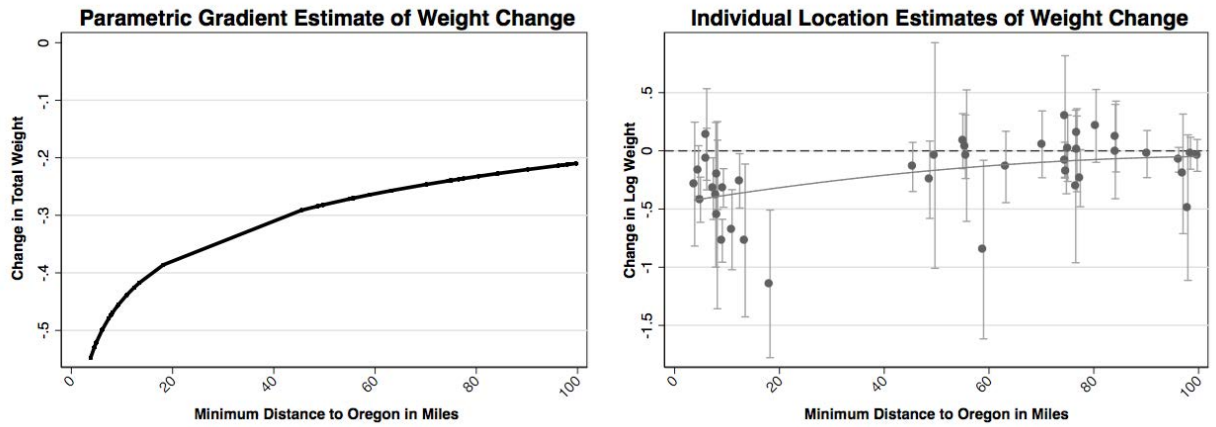
The figure on the left plots the sum of the first two coefficients in Table 4 Column (5); that is, it is a plot of the change in weight sold when Oregon's recreational marijuana market opens by distance to the border. The figure on the right plots the response (and 95 percent confidence interval) on October 1, 2015 of each individual retail location within 100 miles of the Oregon border. The response for each retail location is estimated separately for each firm using the estimating equation 1. A quadratic line is fitted through these individual location estimates.

**Figure 3: Retail Weight Response by Transaction Size at Oregon Border**
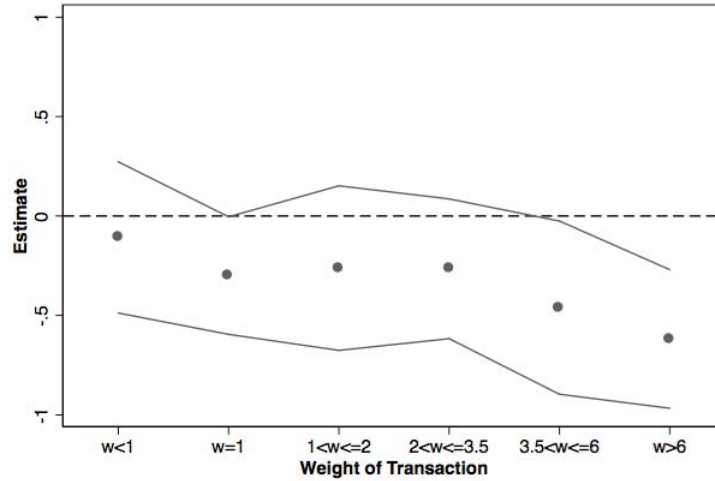
This figure examines how the weight response varies by the size of the marijuana transaction. The dots mark the estimates for each transaction size range and the lines mark the 95% confidence intervals around these estimates. The splits are at the 5th, 25th, 50th, 75th, and 90th percentiles of marijuana transaction size for Oregon, Idaho and Canadian border counties in Washington in the two months preceding the opening of Oregon's recreational marijuana market. The dots mark the estimates for each transaction size and the lines mark the 95% confidence intervals around these estimates.

Figure 4: Oregon Border Retail Bandwidth and Polynomial Choice Sensitivity
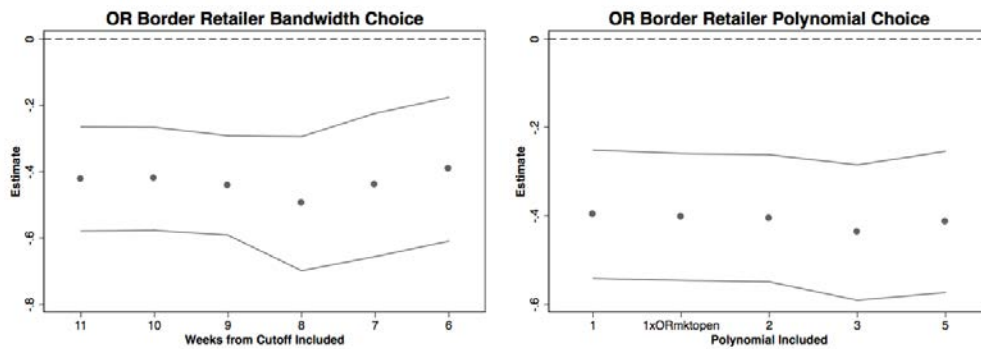
The figure on the left considers the sensitivity of the estimates in Column (1) of Table 5 to the number of weeks of data we include on either side of the tax change. The dots mark the estimates for each bandwidth choice and the lines mark the 95% confidence intervals around these estimates. The figure on the right considers the sensitivity of the estimates in Column (1) of Table 5 to the polynomial order chosen. We consider linear, quadratic, cubic, quintic, and linear interacted with the Oregon market opening indicator. The dots mark the estimates for each polynomial choice and the lines mark the 95% confidence intervals around these estimates. These polynomials are interacted with county indicator variables.

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Figure 5: Estimated Quantities Diverted to WA Border States
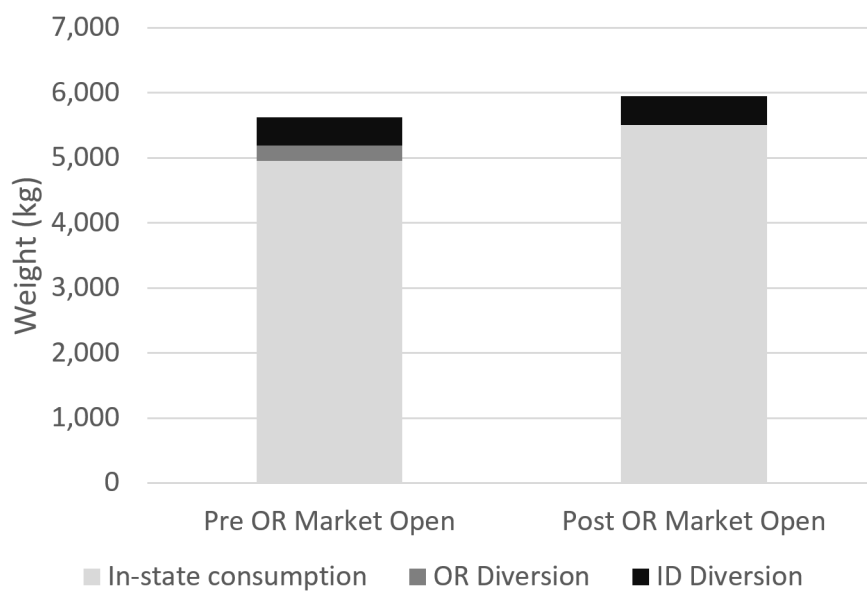
This figure is the result of applying the estimates in Table 3 to the quantities of usable marijuana sold in Washington's border counties in the two months before and after Oregon's market opened, as reported in Table 2.

Appendices

A Figures and Tables for Idaho and Canadian Borders

In this appendix, we provide placebo analyses for our main estimates. In particular, we repeat the tables and figures found in the text (except Table 5) for the Washington counties that border Canada and Idaho. We expect if our model is well-specified and firms are behaving smoothly through the threshold of Oregon's market opening that we should find no significant results in this appendix.

Table A.1 replicates Table 4 in the main text. We find no estimates significant at the 5 percent level or smaller in this appendix and the coefficients are all substantially smaller. Figure A.1 replicates the individual retail location estimates by distance to the Idaho and Canadian borders found in Figure 2. The gradient is completely flat by distance to the Canadian border. It also appears flat along the Idaho border, although estimating a gradient by distance to the Idaho border is challenging as there is only one firm in Washington between 40-100 miles from the Idaho border.

Figure A.2 replicates Figure 3 in the main text for the Idaho and Canadian borders. We see that the estimates are generally small and insignificant across transaction sizes.

Table A.2 replicates Table 6 in the main text. We find no estimates significant at the 5 percent level or smaller in this appendix and the coefficients are about an order of magnitude smaller. Figure A.3 replicates Figure 4 for the Idaho and Canadian borders. The estimates remain near zero and insignificant for all bandwidth choices. The estimates are more sensitive to our choice of polynomial. The estimates highlight that lower-order polynomials do not do a good job of capturing the non-linearities in demand. The higher-order polynomials (3rd and 5th order) both produce estimates that are small and near zero.

Table A.3 replicates Table 7 in the main text, which examined other outcomes when Oregon opened its recreational marijuana market. Here we find only one significant result:

tax-inclusive prices increased in Idaho and this increase is significant at the five percent level; perhaps several firms along the Idaho border decided to decrease their prices around this date and this created the significant result or alternatively the preferences of consumers changed.[28]

<div align="center">

Table A.1: Border Retail Weight Response by Distance

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	(1) 0mi-25mi	(2) 25mi-50mi	(3) 50mi-75mi	(4) 75mi-100mi	(5) Gradient
		Idaho Border Counties			
OR Mkt. Opens	0.023	−0.069	−0.153	-	−0.024
	(0.044)	(0.039)	(0.334)	-	(0.181)
OR Mkt. Opens x Log Distance to ID Border					−0.018
					(0.057)
Log Distance to ID Border					−0.880
					(0.570)
Distance to ID Border Included:	0mi-25mi	25mi-50mi	50mi-75mi	75mi-100mi	0mi-100mi
Observations	951	1,208	103	0	2,262
R-squared	0.917	0.915	0.802	-	0.430
Retail Firms	8	10	10	0	19
		Canadian Border Counties			
OR Mkt. Opens	0.060	−0.116	−0.018	−0.107	0.188
	(0.103)	(0.148)	(0.059)	(0.051)	(0.280)
OR Mkt. Opens x Log Distance to CAN Border					−0.052
					(0.067)
Log Distance to CAN Border					0.146
					(0.178)
Distance to CAN Border Included:	0mi-25mi	25mi-50mi	50mi-75mi	75mi-100mi	0mi-100mi
Observations	951	759	1,188	2,679	5,577
R-squared	0.917	0.740	0.752	0.876	0.378
Retail Firms	8	7	10	23	48

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

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[28]In Hansen et al. (2017), we highlight that these price estimates can include compositional changes and consider inventory lot-day level estimates as an alternative that holds these compositional changes constant. We find very small and insignificant responses at both the Idaho and Canadian borders when we conduct this analysis, suggesting that there was an adjustment in the preferences of consumers along the Idaho border around October 1, 2015.

Table A.2: Robustness Checks for Retail Weight Response in Border Counties

|	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
				Idaho Border Counties				
OR Mkt. Opens	−0.035	−0.009	−0.016	−0.023	−0.033	−0.034	−0.044	−0.033
	(0.028)	(0.019)	(0.032)	(0.030)	(0.028)	(0.027)	(0.029)	(0.028)
Observations	2,039	2,039	2,039	2,039	2,039	2,039	2,039	2,039
R-squared	0.899	0.899	0.899	0.890	0.914	0.898	0.900	0.897
Retail Firms	17	17	17	17	17	17	17	17
				Canadian Border Counties				
OR Mkt. Opens	−0.021	0.024	0.006	−0.031	−0.024	−0.018	−0.019	−0.022
	(0.072)	(0.066)	(0.084)	(0.073)	(0.074)	(0.068)	(0.072)	(0.071)
Observations	1,838	1,838	1,838	1,838	1,838	1,838	1,838	1,838
R-squared	0.865	0.864	0.865	0.859	0.875	0.863	0.865	0.850
Retail Firms	16	16	16	16	16	16	16	16
Indicators for Sept.30 and Oct. 2?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Indicators for Sept. 29 and Oct. 3?	No	No	Yes	No	No	No	No	No
Indicators for Holidays?	No	No	Yes	No	No	No	No	No
Weekend Days x Retail Location?	No	No	No	Yes	No	No	No	No
Processor Prices Included?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
# Competitors Included?	No	No	No	No	No	No	Yes	No
County x Polynomial Included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions unless otherwise specified in the table above: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Table A.3: Responses of Additional Variables at Border

|	(1) Weight	(2) TI Price	(3) TI Rev.	(4) Sales	(5) Inv.	(6) THC
			Idaho Border Counties			
OR Mkt. Opens	−0.035	0.034*	−0.014	−0.027	−0.040	0.003
	(0.028)	(0.016)	(0.028)	(0.042)	(0.085)	(0.010)
Observations	2,039	2,039	2,039	2,039	2,039	2,039
R-squared	0.899	0.935	0.901	0.893	0.901	0.651
Retailer Locations	17	17	17	17	17	17
			Canadian Border Counties			
OR Mkt. Opens	−0.021	−0.028	−0.033	−0.005	−0.052	0.001
	(0.072)	(0.018)	(0.069)	(0.058)	(0.119)	(0.026)
Observations	1,838	1,838	1,838	1,838	1,838	1,838
R-squared	0.865	0.677	0.885	0.925	0.929	0.566
Retailer Locations	16	16	16	16	16	16

The dependent variable is listed below the column number for each retail sales location-day. TI stands for tax-inclusive. Inv. stands for the inventory at the start of the day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Figure A.1: Retail Weight Response by Distance to the Idaho or Canadian Border
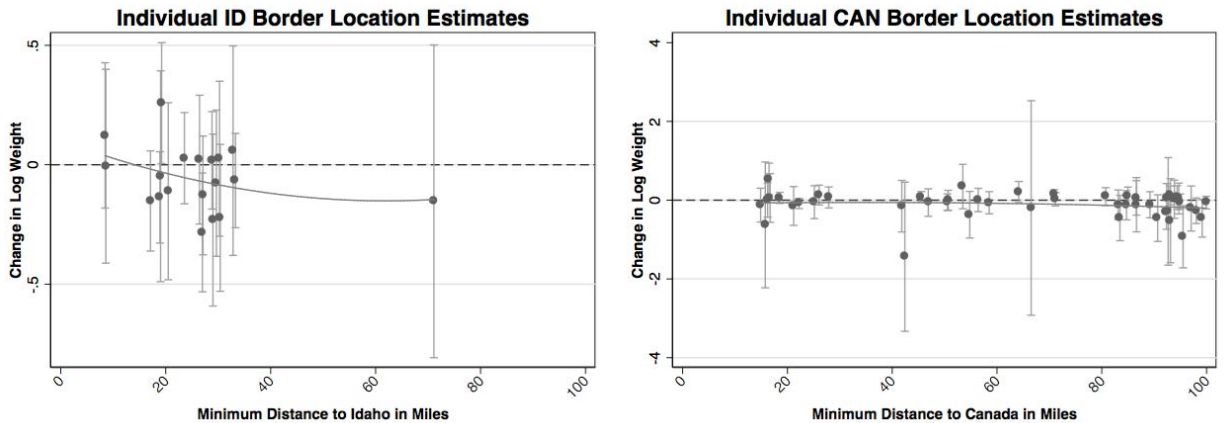

These figures plot the response (and 95 percent confidence interval) on October 1, 2015 of each individual retail location within 100 miles of the Idaho or Canadian borders. The response for each retail location is estimated separately for each firm using the estimating equation 1. A quadratic line is fitted through these individual location estimates.

Figure A.2: Border Retail Weight Response by Transaction Size
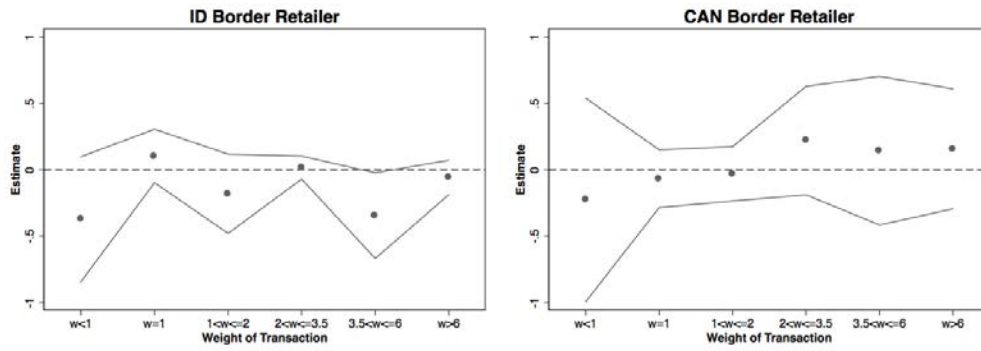
This figure examines how the weight response varies by the size of the marijuana transaction along the Idaho and Canadian borders. The dots mark the estimates for each transaction size range and the lines mark the 95% confidence intervals around these estimates. The splits are at the 5th, 25th, 50th, 75th, and 90th percentiles of marijuana transaction size for Oregon, Idaho and Canadian border counties in Washington in the two months preceding the opening of Oregon's recreational marijuana market. The dots mark the estimates for each transaction size and the lines mark the 95% confidence intervals around these estimates.

Figure A.3: Retail Bandwidth and Polynomial Choice Sensitivity
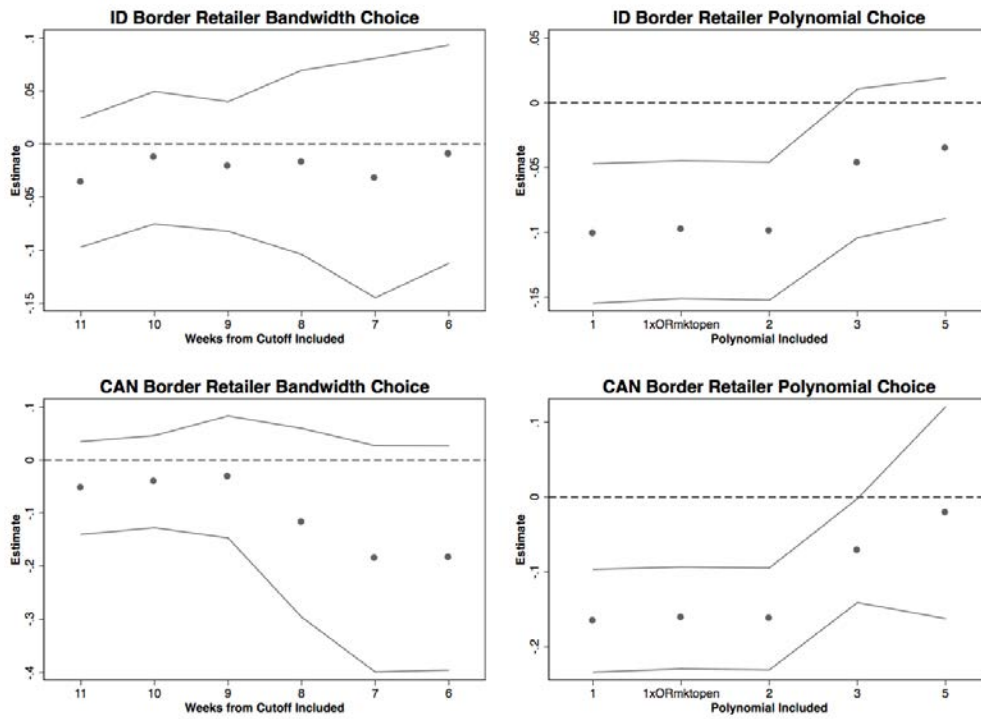
The figures on the left consider the sensitivity of the estimates in Column (1) of Table A.1 to the number of weeks of data we include on either side of the tax change for Idaho (top) and Canada (bottom). The dots mark the estimates for each bandwidth choice and the lines mark the 95% confidence intervals around these estimates. The figure on the right considers the sensitivity of the estimates in Column (1) of Table A.1 to the polynomial order chosen for Idaho (top) and Canada (bottom). We consider linear, quadratic, cubic, quintic, and linear interacted with the OR Market Open indicator. The dots mark the estimates for each polynomial choice and the lines mark the 95% confidence intervals around these estimates. These polynomials are interacted with county indicator variables.

# B Figures and Tables for Oregon's Introduction of Tax on Marijuana

In this appendix, we examine whether demand in Washington responds to Oregon's introduction of a 25 percent tax on marijuana on January 4, 2016. Table B.1 replicates Table 3 and Figure B.1 replicates Figure 1, but instead of the indicator of interest being when Oregon's recreational marijuana market opened, we move the indicator of interest to be when Oregon introduced a 25 percent tax change. With this movement in time, the relevant holiday indicators also changed. The holiday indicators in these regressions are November 24 - November 29 (Thanksgiving), December 22 - December 27 (Christmas), and December 31 - January 2 (New Year's). We do not include any local adjustment response as it appears none is needed. Both the table and figures suggest no response to the introduction of Oregon's 25 percent tax. Likewise, the quantity of marijuana sold did not change in the Idaho or Canadian placebo analyses. The differences-in-RD estimates similarly suggest the quantity of marijuana sold in Oregon border counties did not change in response to the major tax increase and accompanying price shock in Oregon. While the naive difference-in-difference estimates in B.1 Column (5) provide a positive point estimate, its divergence from the differences-in-RD estimate suggests the underlying common trends assumption in the difference-in-difference estimate is violated, biasing the difference-in-differences estimates upwards (including controls for non-linear trends that vary by county appear to be quite important for this analysis).

Table B.1: Retail Weight Response to Oregon's Tax Change for Border Counties

	(1) OR Border	(2) ID Border	(3) CAN Border	(4) Combined	(5) DD
OR Border: OR Tax	−0.053			−0.034	0.210***
	(0.047)			(0.044)	(0.041)
ID Border: OR Tax		0.002		0.006	
		(0.041)		(0.038)	
CAN Border: OR Tax			−0.061	−0.065	
			(0.057)	(0.055)	
Counties Included:	OR Border	ID Border	CAN Border	All Borders	All Borders
Observations	2,265	2,075	2,209	6,457	6,457
R-squared	0.915	0.913	0.878	0.922	0.914
Retailer Locations	22	19	24	63	63

The dependent variable is the log of total weight sold for each retail sales location-day. The following variables are included, but not reported in these regressions: log processor price, whether any competitors, log competitors' processor price, day indicator variables for September 30 - October 2, holiday fixed effects, day of the week and day of the month indicator variables, retail location fixed effects, a fifth-order polynomial in retail sale date, and this polynomial interacted with county indicator variables. Standard errors clustered by retail firm are in parentheses. *** significant at the 5% level; ** significant at the 1% level; * significant at the 0.1% level.

Figure B.1: Retail Weight Response to Oregon's Tax Change for Border Counties
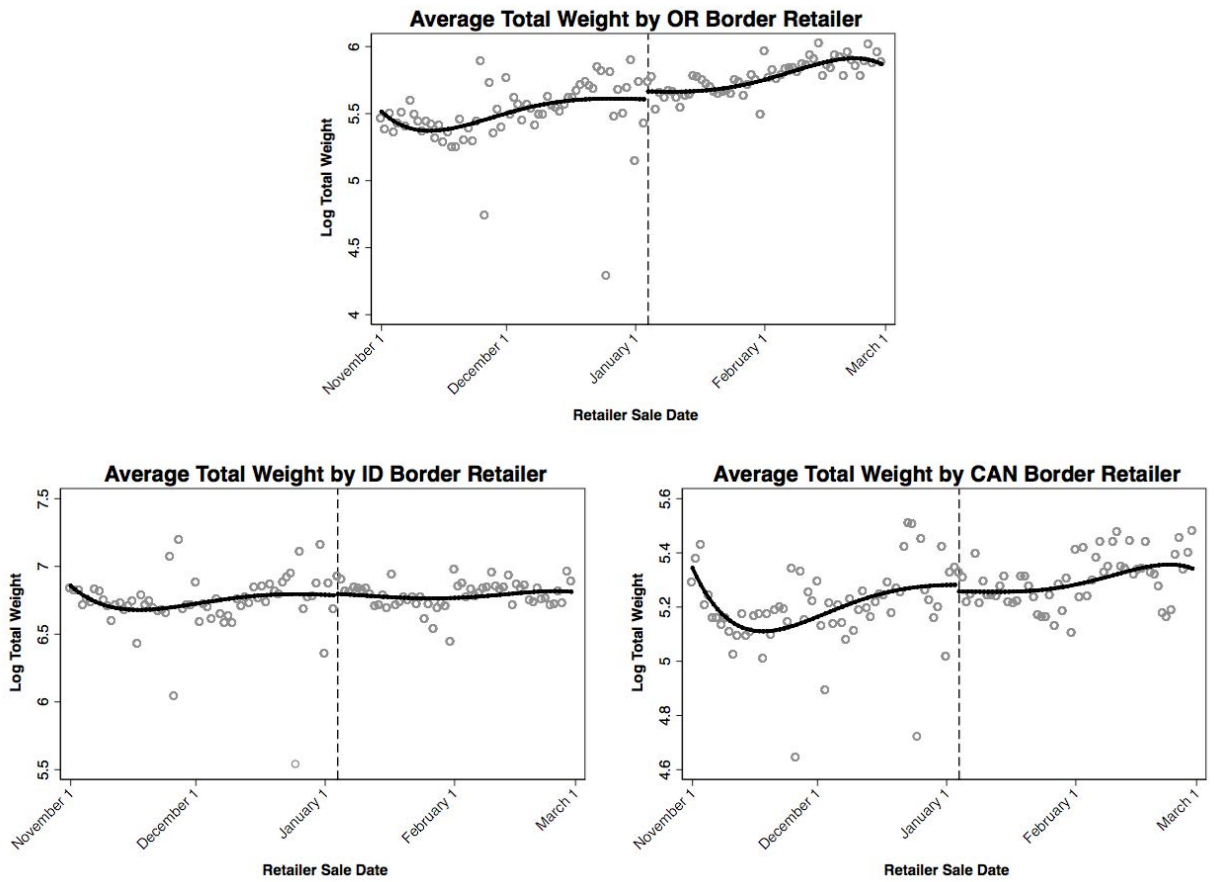
These figures illustrates the shifts in total weight per retail location surrounding the the introduction of Oregon's 25 percent tax on marijuana that are estimated in Column (1) - (3) of Table B.1 by plotting the raw data. The fitted line in the figures plots a fifth-order polynomial through the raw data (allowing for a jump when Oregon's market opened), while controlling for only cyclical trends (day-of-month and day-of-week effects). The hollow circles plot the raw data with the cyclical trends removed. The vertical dashed line marks the day Oregon introduced its 25 percent tax, January 4, 2016.