RAND SOCIAL AND ECONOMIC WELL-BEING

After the Grand Opening

Assessing Cannabis Supply and Demand in Washington State

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Preface

The cannabis policy landscape is changing dramatically in the Americas. More than 25 percent of the U.S. population now lives in states that have passed laws to create commercial legal regimes, and, in 2013, Uruguay became the first country in the modern era to legalize cannabis production and sales. In June 2018, Canada became the second country to legalize cannabis sales for nonmedical purposes, and retail stores opened there in October 2018.

In the United States, Washington and Colorado were on the frontier of these policy changes. Voters in both states passed legalization initiatives in November 2012. Whereas Colorado built on its existing regulatory system for medical cannabis, Washington State's initiative essentially created a new regulatory structure for cannabis, modeling much of the language on Washington's alcohol policies and collaborating with Colorado throughout the process.

To inform these initial efforts, the Washington State Liquor and Cannabis Board (WSLCB) asked the RAND Corporation and BOTEC Analysis to estimate the size of the cannabis market circa 2013. Much has changed since RAND published *Before the Grand Opening: Measuring Washington State's Marijuana Market in the Last Year Before Legalized Commercial Sales* (RR-466-WSLCB), and this report, also conducted for the WSLCB, updates that analysis.

The intended audience for this report is decisionmakers in Washington State tasked with shaping cannabis policy. The methods applied herein should also be of interest to researchers and analysts in other jurisdictions that have implemented or are considering cannabis legalization.

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This report provides detailed information about state-legal cannabis production and sales in Washington, as well as insights about the total amount of tetrahydrocannabinol (THC) obtained from legal and illegal sources by Washington residents. Using data from Washington's traceability system, the authors estimate that approximately 26 metric tons (MT) of THC were sold in the licensed retail stores in Washington from July 1, 2016, through June 30, 2017. About 18 MT were from flower, 6 MT from extracts for inhalation, and the remaining 1–2 MT from other products. This 26 MT is more than double the amount of THC sold in licensed stores in the previous year. Calculating the total amount of THC obtained by residents via legal and illegal sources is difficult with existing data sources, but using additional data from the National Survey on Drug Use and Health and a survey of cannabis users in Washington, author calculations suggest that in the third year after implementing a regulatory system for cannabis, between 40 percent and 60 percent of THC obtained by state residents was likely purchased in Washington's state-licensed stores. Learning more about why some residents are still obtaining cannabis products through other channels, what share of legal sales are to nonresidents, and the efficiency of various cannabis products at delivering THC and other cannabinoids would be fruitful areas for future analysis.

Acknowledgments

We thank Gaby Weinberger for research support and Washington State Liquor and Cannabis Board officials for helping us understand the traceability data and promoting our web survey. The views presented here represent only those of the authors.

Abbreviations

CBD	cannabidiol
CI	confidence interval
DND	daily or near-daily
FY	fiscal year
MJ	marijuana
MT	metric ton(s)
NSDUH	National Survey on Drug Use and Health
OPM	other plant material
RDAS	Restricted-Use Data Analysis System
SAMHSA	Substance Abuse and Mental Health Services Administration
s.d.	standard deviation
TF-IDF	term frequency–inverse document frequency
THC	tetrahydrocannabinol
WSLCB	Washington State Liquor and Cannabis Board

1. Introduction

The cannabis policy landscape is changing dramatically in the Americas. Roughly 25 percent of the U.S. population now lives in states that have created commercial legal regimes for supplying nonmedical use, and, in 2013, Uruguay became the first country in the world to legalize cannabis production and sales. In June 2018, Canada became the second country to legalize cannabis sales for nonmedical purposes, and retail stores opened there in October 2018.

In the United States, Washington and Colorado were on the frontier of these policy changes. Voters in both states passed legalization initiatives in November 2012. Whereas Colorado built on its existing regulatory system for medical cannabis, Washington State's initiative essentially created a new regulatory structure for cannabis, modeling much of the language on Washington's alcohol policies and collaborating with Colorado throughout the process. To inform its earlier efforts, the Washington State Liquor and Cannabis Board (WSLCB) asked the RAND Corporation and BOTEC Analysis to estimate the size of the cannabis market circa 2013. Much has changed since then, and the WSLCB asked for an update of that analysis.

In some respects, the data situation has significantly improved in the state because of the requirement that all licensed cannabis businesses regularly submit information to the state's "seed-to-sale" traceability database. It has also become easier to estimate the number of cannabis use days in the state with the revival of the National Survey on Drug Use and Health's (NSDUH's) Restricted-Use Data Analysis System (RDAS) (undated). Unfortunately, some data have become more limited with NSDUH's hiatus from administering its cannabis market module in 2015 and 2016.

This report provides a review of state-legal production and sales in Washington, as well as insights about total demand for cannabis products by Washington residents. The next chapter focuses on production and sales since July 2014, and Chapter 3 provides detailed information about cannabis consumption in Washington for fiscal year (FY) 2017 (July 1, 2016 to June 30, 2017). Chapter 4 compares these estimates, and Chapter 5 offers some concluding thoughts.

2. Licensed Cannabis Production and Sales in Washington

This chapter describes the flow of marijuana products through Washington State's regulated marijuana marketplace, as recorded in the seed-to-sale traceability dataset. The dataset spans the entire supply chain. Production begins at harvest, after which plant material is put into lots, then either converted to intermediate products on the way to an extract-based retail product or converted directly to usable cannabis. Those stages encompass more than a dozen product types.

Below, we document the changing cannabinoid content, production, and sales volume for all such products for which data are available. Data on production volumes are presented to describe the increasing scale of regulated cannabis activity in Washington State, and the types of products constituting it. The volume of production activity is expressed in several measures, including number of plants harvested, the weight of harvested material, net weight of intermediate products, and the quantity (and net weight, where applicable) of retail products that were manufactured (but not necessarily sold). To provide a supplementary perspective, data pertaining to volumes of retail sales are also presented. The volume of retail activity is measured in several ways, including number of units sold, product weight (where applicable), and dollar value. For both production and retail sale, aggregate production is also provided in terms of the total weight of cannabinoid content.

From a public health perspective, there is great interest in the tetrahydrocannabinol (THC) and cannabidiol (CBD) content of cannabis products, as THC is the primary psychoactive ingredient in cannabis, and CBD may mediate some of the effects of THC (see, e.g., Englund et al., 2017). Cannabinoid content is measured either as the concentration (percentage) by weight or content (in milligrams) per retail unit. This chapter also documents the changing contents of THC and CBD in products over time and estimates the total volume of THC and CBD produced in Washington State's regulated market.

The remainder of this chapter is structured as follows. First, we provide an overview of the traceability system and dataset, discussing the range of regulated cannabis products tracked and how they flow through the supply chain and are recorded in the traceability dataset, and then we explain with limitations of the dataset. Next, we document the changing cannabinoid content of Washington's cannabis products, from flower lots to intermediary products to end-retail products. We go on to document the volume of production across the supply chain in terms of number of units, bulk weight of cannabis content (where applicable), and weight of cannabinoid content. To close, we present similar statistics relating to total retail sales.

Use of the Traceability Dataset

The traceability dataset is available to the public upon request and contains data from events from early 2014 through the end of October 2017. The dataset consists of mandatory reports from cannabis licensees to the seed-to-sale system, spanning the entire range of the supply chain, including plantings, harvests, division into lots of flower and other plant material, conversion from one type of product to another, interlicensee product transfers, retail sale, and results of laboratory tests. The dataset consists of 17 database tables, each pertaining to a different type of event or log thereof. The following section describes the flow of products through the supply chain to explain how data are entered into the traceability dataset.

Charting Product Flow and the Range of Cannabis Products

The regulated cannabis supply chain begins with the seed, clone, or plant, held by licensed producers (many of whom also hold processing licenses). Producers are licensed according to one of three tiers based on the maximum allowed square footage of growing canopy: 2,000 square feet (Tier 1), 10,000 square feet (Tier 2), and 30,000 square feet (Tier 3). Washington State regulations define plant canopy as "the square footage dedicated to live plant production, such as maintaining mother plants, propagating plants from seed to plant tissue, clones, vegetative or flowering area. Plant canopy does not include areas such as space used for the storage of fertilizers, pesticides, or other products, quarantine, office space, etc." From the beginning of the regulated market to the end of 2015, Washington's producers were restricted to 70 percent of these canopy limits, raised to 100 percent by the beginning of 2017.[1] These tiers do not specify a given growing method (indoor, greenhouse, or outdoor), although generally smaller (Tier 1) producers are disproportionately likely to be growing indoor, and Tier 3 producers are disproportionately likely to be growing outdoor.

When licensed producers harvest a plant, they produce both "flower" and "other plant material" (OPM) and report to the traceability system the weight of each, along with the weight of any waste material for destruction. While "flower" refers to the most potent part of the cannabis plant, OPM refers to lower-potency parts of the plant, such as leaves and stems. After harvest, flower and OPM are dried and cured, then gathered into bulk lots (allowed up to five pounds). After this point, the remaining path through the supply chain grows more complicated.

The vast majority of flower inside flower lots is dried and cured to produce "usable marijuana," i.e., dried marijuana flower or "bud." Some OPM is also dried and cured but is instead categorized as "marijuana mix package" (and sometimes blended with flower to do so).[2]

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[1] However, the lifting of the 70-percent restriction does not imply that licensees then decided to increase their canopy; many may have not, and the amount of canopy used by each licensee is not reported in the traceability dataset.

[2] While we generally prefer the term *cannabis* to *marijuana*, we refer to the latter in this section because that is the term used in the seed-to-sale system.

The vast majority of OPM, and a small share of flower, undergoes extraction (e.g., to produce an extract for inhalation) and sometimes also infusion (when producing an edible). Some producers with integrated producer/processor licenses perform these services in-house, but most will sell flower lots or OPM lots to a processor licensee. Processors are licensed to produce ingredient products and retail products, though they do not always perform the entire range of services in-house; for instance, one processor might purchase an OPM lot, convert that to food-grade solvent extract, and then sell to another processor who will convert that into an edible before selling to a retailer.

All products must undergo testing at the last point of conversion before arriving at a final retail product. This is necessary both to provide an accurate representation of cannabinoid potency in the final product and to screen for residual solvents or other harmful substances used in the processing. Generally, this involves the processor who created the next-to-final product submitting a small sample to a laboratory for testing. The test results of that sample can then be extrapolated to the population from which it was sampled, e.g., a five-pound flower lot.

Therefore, products in the traceability system can be classified as (a) plant material, (b) lotted plant material, (c) an "ingredient" produced from lotted material, which will later be converted to a retail product, or (d) a retail product, which is produced from ingredients and/or lotted plant material. There are three main conversion events: from plant material to lot, from lot to ingredient, and from ingredient to retail product. A partial exception to this rule is "marijuana mix," which is the only ingredient product eligible for conversion to another ingredient before conversion to a retail product. However, this occurs in only 5 percent of conversions (to either hydrocarbon wax, CO_2 hash oil, hash, or kief); the remaining 95 percent of conversions from marijuana mix directly produced a retail product, such as marijuana mix infused or marijuana mix package. Appendix Table A.1 provides definitions of all inventory types discussed in this report.

Table 2.1 provides simple counts of these conversion events, represented as a matrix with parent products (i.e., lotted material or marijuana mix) on the columns and child products on the rows, grouped as either retail or ingredient products, then arranged in descending order by the number of conversions. This helps illustrate several patterns. First, the bulk of the market is sourced from flower rather than other plant material. The vast majority of flower lot is used to produce usable marijuana, while OPM is almost exclusively used to produce concentrate-based products.

Table 2.1. Count of Valid Conversions to Intermediate Products

Converted to . . .	Flower Lot	Other Plant Material Lot	Marijuana Mix	Total
Ingredients				
Hydrocarbon wax	15,616	13,892	731	30,239
CO_2 hash oil	5,568	6,574	294	12,436
Marijuana mix	6,383	3,914	0	10,297
Kief	3,846	1,580	212	5,638
Food-grade solvent extract	1,957	1,776	108	3,841
Hash	1,886	592	169	2,647
Bubble hash	995	921	48	1,964
Infused cooking oil	230	151	13	394
Infused butter/fat	146	112	21	279
Retail products				
Usable marijuana	1,775,283	0	0	1,775,283
Marijuana mix packaged	0	0	28,200	28,200
Marijuana mix infused	1,590	0	1,883	3,473
All downstream products	1,813,500	29,512	3,179	—

Table 2.2 provides counts of conversion from ingredients (columns) to retail products (rows); ingredients are provided in descending order, left-to-right, by number of conversions, illustrating that the vast majority of ingredient-retail conversions are from hydrocarbon wax or CO_2 hash oil to an “extract for inhalation.” Note: A very small number of clearly invalid conversions (e.g., flower lot to flower), conversions with a single report, and conversions to niche retail types (i.e., capsule, suppository and capsule) are not shown in Table 2.1 or Table 2.2.

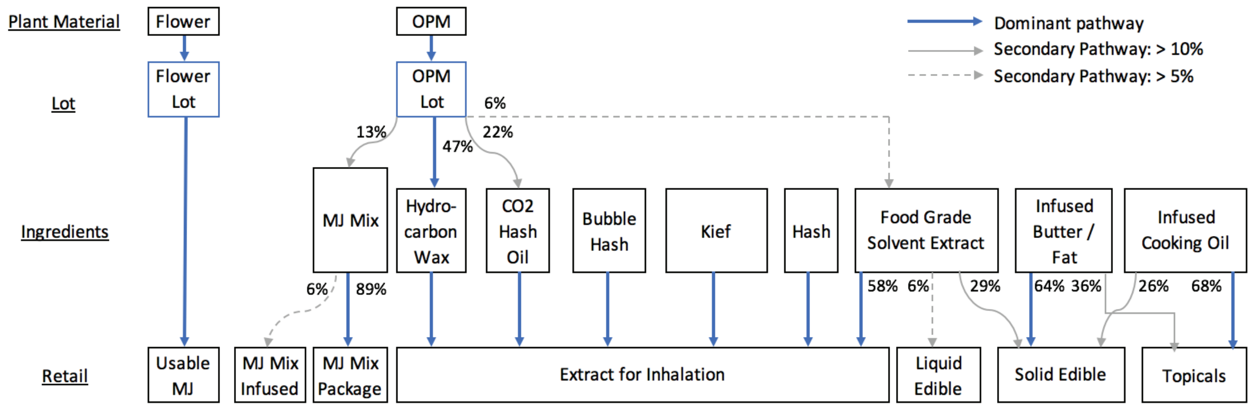
Table 2.2. Count of Valid Ingredient-Retail Conversions

Converted to . . .	Hydrocarbon Wax	CO_2 Hash Oil	Kief	Food-Grade Solvent Extract	Hash	Bubble Hash	Infused Cooking Oil	Infused Butter/Fat	Total
Extract for inhalation	235,512	66,293	10,946	10,317	9,435	5,313	18	6	337,840
Solid edible	3,563	2,395	85	5,129	29	5	413	1,276	12,895
Topicals	495	403	53	880	9	3	1,061	720	3,624
Liquid edible	489	1,348	41	1,436	51	4	68	0	3,437
MJ mix infused	616	217	365	161	267	128	0	0	1,754
All retail products	240,675	70,656	11,490	17,923	9,791	5,453	1,560	2,002	—

NOTE: MJ = marijuana.

Figure 2.1 provides a map of common pathways through this supply chain, produced by counting the number of times each product type was reported to be converted into a product downstream. The figure’s top row indicates plant material, followed by lotted plant material, then ingredient products, and finally retail products. The arrows point “downstream” to each product type’s common destinations, measured by each downstream product’s share of reported conversion events from that product reported to the database. Lines are plotted differently based on pathway prevalence (based on simple counts of events, not adjusted for the volume or weight of each, for simplicity). Pathways accounting for fewer than 5 percent of conversions are not plotted; pathways with between 5-percent and 10-percent prevalence are plotted in dashed gray lines, with accompanying prevalence statistics; pathways with more than 10-percent prevalence but that are not the most common destination are plotted in thin solid gray lines, with accompanying prevalence statistics; finally, pathways with more than 94-percent prevalence are plotted in thick solid blue lines without accompanying statistics. Retail products that were not the most common destination for any ingredients (e.g., liquid edibles) are not shown in this figure.

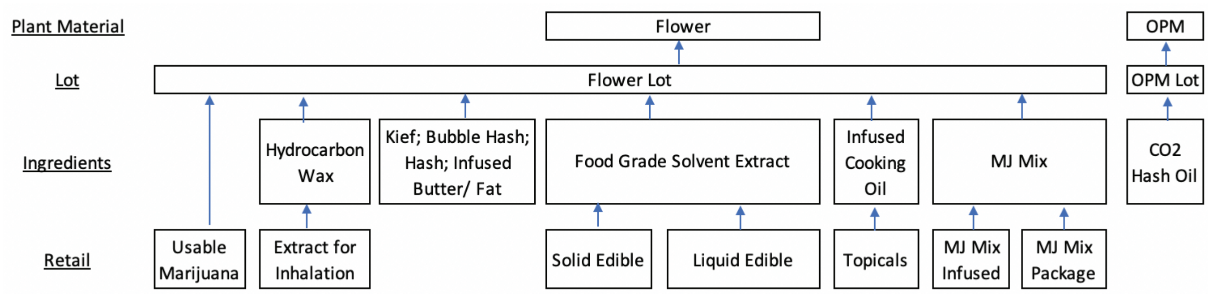
Figure 2.1. Downstream Product Flow, Linked by Most Common Child Product



For instance, flower is exclusively turned to flower lot, which is almost always converted into usable cannabis (96 percent of conversions). OPM lot is most often turned into hydrocarbon wax (47 percent) but also is commonly converted to CO_2 hash oil (22 percent) or marijuana mix (13 percent) and occasionally food-grade solvent extract (6 percent). There are many different possible paths for product to pass through along the supply chain, so for the sake of visual simplicity, the arrows give examples of the flow, rather than an exhaustive catalog. "Extract for inhalation" is the most common destination product for most ingredients, including hydrocarbon wax, CO_2 hash oil, bubble hash, food-grade solvent extract, kief, and hash. "Infused dairy butter or fat in solid form" was converted to solid edibles in 64 percent of reported conversion events, and so the arrow connects it to solid edibles. Still, infused butter/fat was also very commonly converted to extracts for inhalation (the remaining 36 percent of the time), as is the case with marijuana mix and infused cooking oil.

We can complement this picture of the supply chain flow by adding another chart, this time linking products with arrows that point "upstream" to each product's most common ancestor or "source" product (Figure 2.2). This emphasizes that "extract for inhalation" products are most likely to have "hydrocarbon wax" as the source product in a conversion event (70 percent of the time), and in turn hydrocarbon wax is most commonly produced from flower lot (52 percent); OPM lot was the parent product for the other 48 percent of conversions to hydrocarbon wax, but as in the previous chart, this secondary pathway is not visually depicted here. In fact, OPM lot is still a very common source product for many ingredients, accounting for at least 40 percent of reported conversions to bubble hash, food-grade solvent extract, and infused butter/fat and more than 30 percent for marijuana mix and infused cooking oil.

Figure 2.2. Upstream Product Flow, Linked by Most Common Parent Product



At the end of the supply chain are a wide range of retail products. The way these are categorized in the traceability system is not always intuitive, so it is sometimes easier to discuss these as groups of products. The most popular group of retail products relates to dried flower; most of this is sold as "usable marijuana," though a smaller share is in "marijuana mix package" or "marijuana mix infused," which blends marijuana mix package and/or usable marijuana with such extracts as hash or kief to enhance THC content. These marijuana mix products (marijuana mix, marijuana mix package, and marijuana mix infused) were first defined in the data July 1, 2015; before then, presumably, these products tended to be classified as usable marijuana. The category "extracts for inhalation" is its own group of products, comprising mainly oil cartridges for vaporization, solid concentrates for dabbing (e.g., "wax," "shatter," "crumble"), as well as hash, kief, and oil-based concentrates designed for application under the tongue (e.g., colloquially, "Rick Simpson's Oil" or "Phoenix Tears"). The third most popular group of retail products is edibles, which the dataset separates into liquid and solid form. Finally, several products with quite small but growing market shares were added later to the traceability categorization system: topicals, tinctures, suppositories, and capsules.

Use of Dataset Tables for This Report

Analysis in this report makes use of a small number of traceability data tables: "inventory conversions," "dispensing," "lab results," "inventory," "plants," and "plant derivatives." "Lab results" stores the THC and CBD value of each potency test, along with a unique identifier to associate the sample with the population from which it was sampled. "Inventory conversions" reports each time an item is converted from one product to a downstream product. The "dispensing" table holds information relating to the sale of products at retail. "Plants" and "plant derivatives" track information related to the status of plants and occasions where they are harvested, including the material produced by those harvests.

Limitations of the Dataset

The traceability dataset is a complex database, not only in that it consists of many interlocking tables and reports a wide variety of data on a diverse range of cannabis products and production and sales events, but also because it relies on self-reported data from thousands of licensees. It is sometimes unclear what method a licensee used to generate a certain field. The reporting practice used by a licensee can vary for a number of reasons, e.g., the use of a particular inventory-reporting software system, or the type of license, or even that an individual business may decide to change its reporting conventions over time. The database also lacks an official codebook.

Some of these limitations correlate to the fact that the traceability dataset was designed primarily as an enforcement tool (to ensure product remains in the supply chain and adheres to applicable regulations). It may work perfectly in that regard but still be suboptimal for the purposes of broader market surveillance, as we provide here.

These issues are discussed further below, along with explanations of how these limitations were accommodated in the research.

Data reported by licensees are difficult to validate. Data in the traceability dataset come from licensee reports, which are not always accurate. Complicating this is that some licensees seem to follow different methods for reporting certain statistics, so that even if one licensee reports in a coherent and consistent way, it remains difficult to aggregate the data meaningfully without understanding how to interpret each licensee's reports. To some extent, we can attempt to identify anomalous reports by top-coding values set at certain thresholds, e.g., conversions of OPM lot exceeding 6,803 grams (15 pounds), or of retail products exceeding 10,000 units. This is a conservative approach and likely fails to detect some false reports. But without means to individually verify certain reports, it remains unknown whether these thresholds can catch all false reports, or, on the other hand, whether they incorrectly censor accurate data.

A related difficulty is that our analysis makes use of several different database tables, and it is likely that each table has its own types and rates of outliers. To estimate production volume, we rely heavily on the "inventory conversions" table, which is filled with reports from producers and processors and clearly contains a substantial number of anomalous reports. To estimate sales, we rely on the "dispensing" table, which is filled with reports from retailers and appears to be fairly clean. This imbalance in data quality across the two sources makes it difficult to make an "apples-to-apples" comparison of production and retail sales volume, and therefore tabulations of retail sales will exceed tabulations of retail production.

Production data do not consistently distinguish wet and dry weight of plant material. Harvest events are reported in the database titled "plant derivatives," and each time a licensee harvests a plant, it is required to report the weight of any flower or other plant material harvested. However, it is only sometimes indicated whether that weight is taken before or after drying (a process that can reduce weight by nearly 90 percent), and this distinction is never provided for "OPM." This introduces a substantial amount of uncertainty in estimates of the amount of OPM harvested.

Changes in reporting over time prevent comprehensive longitudinal analysis. Due to the change in contractors overseeing the traceability data system, data from the system are available only through the end of October 2017. After this date, licensees were still required to report inventory events, but in the form of weekly spreadsheets, which have not been assembled into an accessible database. Nor have data from the new traceability system yet become available for analysis. In response, we have forecasted harvest, production, sale, and potency data for November and December 2017. The precise method for the forecast varies by type of data (and is further explained in each section). Furthermore, which events are reported in the dataset have changed over time. For instance, the conversion of flower to flower lot and OPM to OPM lot is not reported in the "inventory conversions" table until November 2015; it is not clear whether or where lotting events were reported before that time period. Analysis of the production of lotted material therefore cannot begin until that point in time.

Potency data do not arrive in a meaningful format for several products. For all intermediary products and many major retail product types (usable marijuana, extracts for inhalation, and marijuana mix package and infused), potency test results are provided with THC and CBD values in the form of percentage by weight. This logic breaks down for marijuana-infused solid and liquid edibles, topicals, capsules, and suppositories. Ideally, potency data for these products would arrive in the form of milligrams (mg) of THC or CBD per package, such that the dataset would distinguish a 10mg THC solid edible from a 100mg solid edible. Some THC and CBD observations appear to be reported in this way, but more frequently they represent milligrams per serving (without denoting the number of servings in a package), or concentration by weight (without reporting the physical weight). Nor is there any way in the dataset to identify which formula has been used for which observations. This inhibits estimation of THC or CBD content for these products, and therefore also for the total net weight of cannabinoid content produced or sold in Washington State. To compensate for this deficiency, we have attempted to infer THC content for these products by analyzing the text of inventory labels, which, for a significant portion of products, describe in words the amount of THC and/or CBD in the package. However, there is no uniform format for how to fill out this label field, and it is also often missing, so our team has used text-analytic programs to extract THC content from these observations and machine-learning methods to estimate the content for products without clear labels.

The rest of this chapter is structured as follows. The section on "Measuring Cannabinoid Content" provides estimates of cannabinoid content primarily based on potency test results stored in the "lab results" table; that section's analysis of marijuana-infused edibles also joins the dispensing and inventory tables to estimate THC content of edibles from the text of the product description. The section on "Estimating Production Volume" primarily uses the "inventory conversions" table, although estimates for net-weight of cannabinoid content also make use of the potency data provided in the section prior. The section on "Retail Sales" utilizes the dispensing table to analyze sales volume and product characteristics, joined with data from the lab results table.

Measuring Cannabinoid Content

This section provides data on the THC and CBD content of products throughout the supply chain, from lotted flower, to intermediary "ingredient" products, to end-retail products. For most product types, THC and CBD content is reported as a percentage of weight. Unfortunately, CBD content was not reliably tracked in the traceability dataset until mid-2015, and CBD-A (CBD-"acid") was not reported until March 2016, so CBD content before then is not available in this report. For marijuana-infused edibles, this value cannot be measured from the traceability system, so instead THC content is reported in milligrams per package. We refrain from providing estimates of cannabinoid content for several retail products with unverifiable potency data and very small production and sales volume (topicals, tinctures, capsules, transdermal patches, and suppositories). In all cases, THC and CBD levels are presented in amounts of "Total THC" or "Total CBD" as calculated under Washington State regulations (Total THC = THC + 0.877×THCA), representing estimated molecular weight postdecarboxylation.[3]

Three different methodologies are used to estimate cannabinoid content in this section. For products that have been sold at retail and where net weight is reported at sale (i.e., usable marijuana, marijuana extracts for inhalation, marijuana mix package, and marijuana mix infused), this method is the simplest. Each product's THC and CBD test scores are retrieved from its associated potency test (linking via the "inventoryparentid"); monthly and annual averages are estimated by taking the average of potency content weighted by sales revenue. For the four retail products where net weight is reported at sale, the net weight of cannabinoid content (i.e., kilograms of THC or CBD) can be found by simply multiplying this concentration by the reported product weight. To illustrate the degree of variation in THC and CBD content, for each year and product type, Tables A.2 and A.3 provide the standard deviation of total THC and total CBD content.

This process is slightly more complicated for retail edibles. For these, THC and CBD contents have been estimated using methods based in text analytics and machine learning. This method exploits information in the product label ("productname" field in the dispensing table). First, a text-analytic program using regular expressions extracts the labeled content (in mg) of THC for each item, where available. Sixty-one percent and 53 percent of solid and liquid edibles, respectively, were successfully parsed for THC content.

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[3] Washington Administrative Code 314-55-102. In raw cannabis, e.g., on the flowering plant, these chemicals largely remain carboxylated and are said to exist in the acid form and therefore are denoted as THC-A (THC-"acid") or CBD-A. For these chemicals to yield psychoactive effects, they must first be decarboxylated, a process in which the acid component is removed (i.e., THC-A is converted to THC). When decarboxylation occurs depends on the method of consumption. The dried flower form of marijuana is largely carboxylated and is not decarboxylated until the user applies a source of heat, e.g., a lighter or vaporizer, to consume the material. This case also holds for many forms of marijuana extracts, with the exception of products such as tinctures intended for oral application, which are decarboxylated prior to use. In the consumption of marijuana edibles, decarboxylation largely occurs in the user's digestive tract.

Separately for liquid and solid edibles, a random sample of 100,000 transactions is drawn from the data, and a random forest model is trained on observations with valid extracted THC content and used to estimate the THC content of transactions where THC content could not be extracted. The random forest model has the following features: transaction price, date and time of the transaction (in Unix time, i.e., seconds since 1970), and the interaction of the two; a factor variable representing the census tract in which the transaction occurred, along with the average household income and percentage of population reporting income above $175,000 in that tract; and, lastly, to flexibly capture features of the "productname" text field, a term frequency–inverse document frequency (TF-IDF) matrix constructed from the "productname" text field and reduced to 50 principal components.

By summing together valid observed THC values where available and estimated THC content for observations with invalid THC entries and then multiplying by a scalar quantity to extrapolate to the broader population, we compute aggregate statistics, such as average content per edible or the total weight of THC contained in product sold in a given year or month.

Data on THC and CBD content for marijuana products are provided by way of a sampling-based regime. This creates a good deal of statistical variation, for two primary reasons: (1) Only a small part of a product is actually sampled for testing, and that sample's THC or CBD content may differ from that of the lot from which it was drawn; and (2) methods used by laboratories to measure THC content are not perfectly precise, and practices vary from one lab to another, such that the exact same sample would receive different results from different labs or from the same lab at different times. When aggregated annually, there is a sufficient number of lab tests as to average away most of this variability unless sample selection is not random, e.g., if growers want measured potency to be high and can judge how to sample to send the "best" (most potent) flowers to be tested. However, there can be greater sampling variation when aggregating only a month's data, especially for less common products. For this reason, we smooth data presented relating to cannabinoid content of items from the production side (but not the sales-to-consumer side) when presenting year-monthly plots. To do so, we use a simple moving average, so that each plotted point represents the symmetric average of up to three months forward and backward. For example, since the last full month of data was October 2017, a point plotted in October 2017 is not smoothed at all and represents the data point for that month. The point for September 2017 represents the average of August to October; the point for August represents the average of June to October, etc.

Potency data were forecasted for November and December 2017 to facilitate comparison across calendar years. Given the lack of seasonality in cannabinoid concentrations, the forecasting methodology is fairly simple. Average THC and CBD concentrations (or, in the case of edibles, THC contents in milligrams) for each product type for November and December were set equal to the average of all tests dated in the previous three months (August to October).

Flower Lot

Given that lotted plant material is the earliest point in the supply chain where THC and CBD testing occurs, it is a valuable opportunity to measure the changing potency of cannabis plants in the regulated system. We do not present data on cannabinoid content of OPM, which is never tested at the lot stage; instead, that material will be tested further downstream before conversion to a final product, e.g., as marijuana mix before conversion to marijuana mix package, or as CO_2 hash oil before conversion to an extract for inhalation. Table 2.3 shows increasing THC content of lotted flower, especially relative to the first year, suggesting that licensees have evolved their growing practices and/or their plants' genetics. CBD content remains roughly flat during this period.

Table 2.3. Flower Lot THC and CBD Concentrations, Semiannual

	2014-1*	2014-2	2015-1	2015-2	2016-1	2016-2	2017-1	2017-2
THC (%)	13.52	16.15	18.89	19.2	19.56	19.4	20.94	20.23
CBD (%)	0.02	0.36	0.46	0.48	0.43	0.49	0.38	0.41

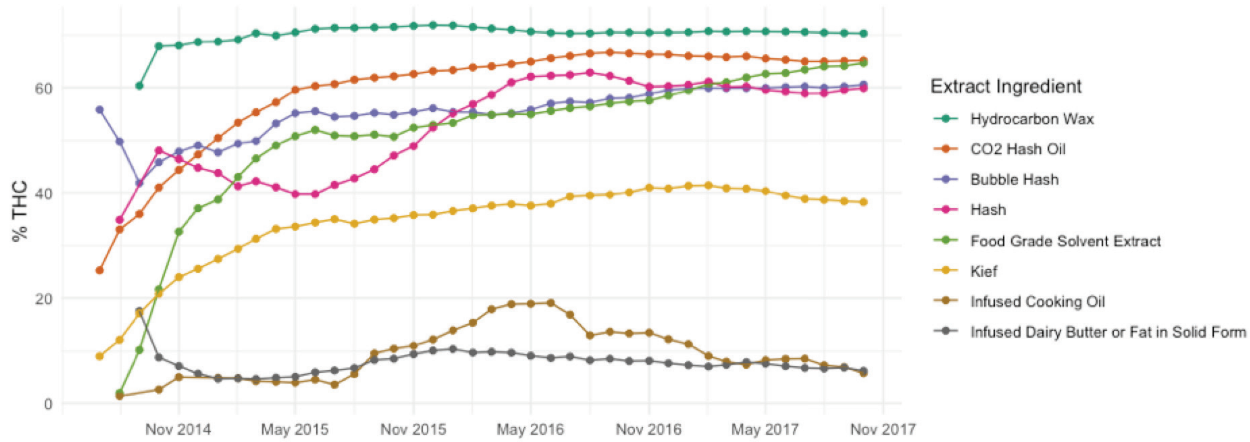
* Averages are not stable in the first half of 2014 due to very small sample size.

Standard deviations for the THC and CBD content of each product type are provided for each year when data are available in the appendix (Table A.2, Table A.3).

Extract Ingredients

The cannabinoid content of extract ingredients is liable to change separately from any trends in the potency of the original plant material, owing to different uses of technology or extraction and infusing processes. This also represents the first point at which other plant material undergoes testing. Table 2.4 provides annual estimates of average THC and CBD for each ingredient product type; Figure 2.3 plots monthly concentrations of THC. Nearly every extract ingredient has seen rising THC concentrations, particularly before mid-2015, but continuing afterward for several products.

Figure 2.3. Extract Ingredient THC Concentrations



Only two products have not shown significant increases in THC concentration: infused cooking oil and infused dairy butter or fat in solid form. Marijuana mix (not shown in Figures 2.4–2.7 and not used in the dataset until mid-2015) shows similar trends but at slightly lower levels, rising from 15.7 percent in the second half of 2015 to 19.2 percent in 2017.[4]

For every ingredient product analyzed, CBD concentrations remain much lower than THC concentrations. However, several products have shown CBD concentrations increasing over time, notably CO_2 hash oil, hash, food-grade solvent extract, and infused cooking oil. The largest increase occurs in CO_2 hash oil, where concentrations in 2017 are more than double those measured in 2015. Food-grade solvent extract peaked in CBD in 2016 before falling somewhat in 2017. One explanation for these trends is a rising prevalence of CBD-based products.

Table 2.4. Extract Ingredients: THC and CBD Content, Annual

	Percentage THC				Percentage CBD		
Extract Ingredient	**2014**	**2015**	**2016**	**2017**	**2015**	**2016**	**2017**
Hydrocarbon wax	67.5	71.3	70.4	70.6	5.4	8.1	7.2
CO_2 hash oil	38.6	60.3	65.7	65.2	2.6	3.8	5.4
Bubble hash	43.2	55.1	57.2	60.2	1.7	2.3	1.9
Hash	48.2	41.3	62.1	59.0	1.2	1.5	2.0
Food-grade solvent extract	21.7	51.9	56.1	62.9	1.0	2.2	1.2
Kief	19.5	34.5	38.5	39.1	0.2	1.8	2.1
Marijuana mix	—	15.7	17.5	19.0	0.7	0.7	0.6
Infused cooking oil	2.7	4.2	17.8	8.2	0.3	0.4	0.3
Infused dairy butter or fat in solid form	7.2	6.3	8.9	7.0	0.1	0.2	0.0

[4] Because CBD content was not consistently reported in 2014, those figures are suppressed from the annual tables below; to preserve visual appeal, marijuana mix appears in Table 2.4.

Retail Products

For four retail products (marijuana extract for inhalation, marijuana mix infused, marijuana mix package, and usable marijuana), potency data from the traceability dataset is recorded as concentration by weight. These products make up the vast majority of production and sales in Washington State. Table 2.5 reports average THC and CBD concentrations for these products on an annual basis.

Table 2.5. Extracts and Flower-Based Retail Products: THC and CBD Content, Annual

	Percentage THC				Percentage CBD			
Retail Product	**2014**	**2015**	**2016**	**2017**	**2014**	**2015**	**2016**	**2017**
Extract for inhalation	40.9	63.1	69.6	70.3	1.2	1.7	2.1	2.7
Marijuana mix Infused	—	33.3	30.1	35.0	—	0.6	0.7	0.7
Usable marijuana	16.5	19.8	20.5	21.4	—	0.3	0.3	0.4
Marijuana mix package	—	19.4	19.6	21.4	0.2	0.4	0.4	0.4

Flower-based products show consistently rising THC content. Usable marijuana, the dominant product in the market, has risen from 16.5 percent THC in 2014 to 21.4 percent in 2017. Since the definition of marijuana mix package in mid-2015, its THC concentration has risen from 19.4 percent in 2015 to 21.4 percent in 2017. CBD concentrations remain extremely low among flower-based products, at 0.4 percent in 2017 for both usable marijuana and marijuana mix package. This indicates that the vast majority of marijuana products on sale in Washington State contain near-negligible amounts of CBD.

Marijuana extracts for inhalation have shown substantially larger increases in THC. Data from 2014 (which may be unreliable due to small sample size and changing business practices of licensees) average 40.9 percent THC. From 2015 to 2017, THC concentrations rose from 63.1 percent to 70.3 percent. CBD concentrations also rose among extracts, more than doubling from 1.2 percent in 2014 to 2.7 percent in 2017.

Data-quality issues in the traceability dataset prevent the estimation of THC and CBD content with the same level of precision for marijuana edibles, as noted earlier in this section. Table 2.6 provides estimates of the average THC content (mg) per edible by year; data from 2014 are suppressed due to the low volume of edibles sold in that year. Potency data estimated from this process suggest that liquid edibles tend toward higher THC content than solid edibles (70.6 mg and 57.5 mg, on average, respectively, in 2017). THC content among liquid edibles appears to have been flat since 2016, while estimated THC content in solid edibles has increased consistently since 2015.

Table 2.6. Average Estimated THC Content (mg) in Edibles

	2015	2016	2017
Liquid edibles	61.5	70.1	70.6
Solid edibles	43.6	48.4	57.5

Estimating Production Volume

Production volume is analyzed and reported here in the same order as product flows through the supply chain. This chapter relies heavily on the two tables through which all product must pass, from harvest to eventual conversion to an end product: "plant derivatives" and "inventory conversions."[5] Analysis of these tables therefore provides a means to estimate total production in the supply chain. Due to the abrupt end of data after October 2017, to facilitate year-to-year comparisons, the final two months of data were forecasted based on historical comparison (with somewhat different methods by type of activity, discussed in further detail below). These forecasted data are used to compute annual and semiannual aggregations but are not displayed in the accompanying charts.

After forecasting and data cleaning, we use these data to estimate the following: (a) the production volume (grams) of flower lot, OPM, and other nonretail products, (b) the production volume (number of retail packages) of retail products, and (c) the production volume (net weight) of the four types of retail products where specific weight measures are interpreted, i.e., usable marijuana, extracts for inhalation, marijuana mix infused, and marijuana mix package. The section is organized into the following subsections, accompanied by tabulations of semiannual production and brief explanations of the products involved: harvest events, lotting, conversion to extract ingredients, and manufacture of retail products.

Plant Material Harvested

Each time a licensee harvests a marijuana plant, the licensee makes a report to the "plant derivatives" table, along with the associated weight of the output for as many as three types of output: wet flower, OPM, and waste. Table 2.7 provides estimates of annual production. Harvested flower provides the bulk of cannabinoid content that is eventually converted into end products, but OPM also plays a significant role. In 2016, more than 55 percent of plants were recorded to have been harvested for OPM.

Weights of flower after drying (dry weight) are reported separately from the weight before drying (wet weight); however, no such distinction is made for OPM. Therefore Table 2.7 shows only one column for OPM but two for flower (dry and wet). Although most harvest entries appear valid and accurate, a small number contain extremely large values that appear inaccurate (e.g. 88,888,888). To get rid of these gross outliers even at the expense of sacrificing some

[5] Except as discussed below, harvest data are missing from the plant derivatives table prior to November 2015.

accurate data points, any values above the 99th percentile of the distribution of OPM weights were removed from analysis.

Marijuana harvests show very strong seasonal trends, generally rising sharply in October and peaking in November. Because data were unavailable after October 2017, to facilitate year-to-year comparisons, the rest of 2017 was forecasted using historical comparison to the share of production accounted for in those months during previous years. Making the assumption that this parameter in 2017 would resemble that observed in 2015 and 2016, we estimated that January–October production would account for roughly 85 percent of all production in 2017 and inflated accordingly.

Table 2.7. Number of Plants Harvested and Weight of Harvest Material (MT)

Year	Plants (1,000s)	Wet Weight (MT)	Dry Weight (MT)	OPM Weight (MT)	Grams-per-Plant
2014	147	86.6	14.2	15.0	96.6
2015	1,010	544.4	80.1	65.1	79.3
2016	1,872	1,294.8	190.9	133.1	102.0
2017	2,109	1,410.1	225.3	86.7	106.9
2017 projected	2,460	1,659.0	265.5	101.2	107.9

NOTE: MT = metric ton(s).

Though it would be interesting to know the total weight of cannabinoid content at this stage, it is not until the lotting stage that harvested flower will be tested (and further downstream for other plant material).

Flower and OPM Lots

After the point of harvest, all conversions from one product to another (which are defined to always move downstream, or further along the supply chain) are stored in the “inventory conversions” table. This can be as simple as dry flower from multiple plants being grouped into a flower lot, or CO_2 hash oil being manufactured into an extract for inhalation product. As this table is fairly complicated and the data contained are rife with anomalous entries, an explanation of how these data are interpreted and cleaned is provided here before results are displayed.

Each conversion reports both the “parent” and “child” product type, along with the quantity of the child type produced. To estimate the volume of conversions, we use two values from this table, with interpretations that vary based on the associated product type. First is *childweight*. For most nonretail products, this refers to the weight (in grams) of the product produced from a particular conversion event; for retail products, this instead measures quantity (in terms of number of retail packages). Second is “childusableweight.” For this report, *childusableweight* is interpreted for only four retail products: usable marijuana, extracts for inhalation, marijuana mix infused, and marijuana mix package. These are the only products where childusableweight appeared to be consistently reported and therefore reliably interpreted. For these products, this value clearly and consistently measures products' total weight (grams) before packaging. This value appears alongside childweight, so an entry for usable marijuana with childweight = 10 and childusableweight = 350 indicates ten different retail packages, each containing 3.5 grams of dried flower. (For products other than these four retail types, childusableweight was either consistently identical to childweight, and therefore unnecessary for analysis, or very frequently negative-valued or missing, such that it could not be meaningfully interpreted as a measure of product content.)

We clean the values in these fields to protect against high-valued anomalies. First, we top-code values in childweight with different values depending on the product type. For "Flower Lot" and "OPM Lot," we top-code at 6,803 (roughly 15 pounds). Testing regulations effectively prohibit OPM lots above 6,803 grams and flower lots above five pounds or 2,267 grams. For other nonretail products, we also top-code values at 6,803, following the logic that these products are generally produced from lots of OPM or flower and therefore should not weigh more than the original lot.[6] For retail products, we top-code values at 10,000 (where *childweight* refers to the number of retail packages). For most product types, this top-coding affects less than 1 percent of all observations. Finally, we top-code the values of childusableweight for the four product types where this value is interpreted. In these cases, *childweight* indicates the number of retail packages and *childusableweight* indicates the total net weight across them; therefore, the weight-per-package can be calculated as childusableweight divided by childweight. We top-code the values for childusableweight, enforcing the rule that retail packages cannot exceed one ounce (28.5 grams) of marijuana for flower and extract-based products.

Table 2.8 provides semiannual estimates of the production of flower lot and OPM lot. For an unknown reason, data on lotting is unavailable in the dataset until November 2015. Accordingly, Table 2.8 does not report any lot production before then, and estimates for the second half of 2015 are marked with an asterisk to indicate that these values do not represent a full half-year.

For an unknown reason, flower and OPM lot production are not reported in the "inventory conversions" table until November 2015. Production volumes are displayed from that date onward. Data on lotting activity were also forecasted using an analogous method to that used to forecast harvest activity in Table 2.7. Forecasts are based off of the share of activity in November or December relative to total activity from January to October in 2016. For example, the weight of flower lot produced in November 2016 was 67.4 percent of what had been reported from January to October 2016; from January to October in 2017, 73.7 MT of flower lot were

[6] There are cases when this might not be accurate. First, a processor might have combined several 15-pound OPM lots into a single larger lot before converting them into a downstream product, though this seems rare. Second, the weight of some child products in a conversion could exceed the weight of the parent, e.g., in the creation of infused dairy butter or fat in solid form, where the parent weight refers to the weight of the lotted flower or OPM, but then other nonmarijuana products, such as dairy products, are added in the conversion process to yield the child product, which might weigh more than the parent due to the combined weight of its marijuana and nonmarijuana content. Therefore, this method might underestimate the production volume in some cases, but the data suggest these are relatively rare.

produced, so production for November 2017 was forecast as 49.7 MT, holding constant the 64.7 percent relative share. Similar calculations were made for OPM Lot and all other units produced downstream.

Table 2.8. Flower and OPM Lot: Production Volume (MT), Semiannual

Type of Bulk Plant Material	2015-2	2016-1	2016-2	2017-1	2017-2
Flower lot*	28	49	121	87	170
OPM lot*	11	25	59	37	84

* Production data not available until November 2015.

Extract Ingredients

After flower and OPM have been aggregated into lots, they are eligible for conversion into downstream products. Flower lot (but not OPM lot) may be converted directly into the retail product usable marijuana; in that case, this product would not be reflected in the volume of production of extract ingredients. Alternatively, flower lot—like all OPM lot—may be converted to an intermediary ingredient product, which may later be converted into a downstream retail product. Note that a small portion (roughly 5 percent) of marijuana mix is converted into another ingredient product before conversion to a final product (e.g., to CO_2 hash oil). Therefore, it is not strictly correct to simply sum up each individual product's production volume to arrive at a total estimate. However, this represents a small share of marijuana mix, and it is the only ingredient product that can be converted into another ingredient product before conversion to a retail product. Figure 2.4 charts the total estimated weight of THC produced per year-month for each extract ingredient (grouping together hash and bubble hash for simplicity). Tables 2.7, 2.8, and 2.9 provide estimates for bulk weight of each, along with weight of THC and CBD.

Figure 2.4. THC-Weight of Material Used to Make Extracts (kg)

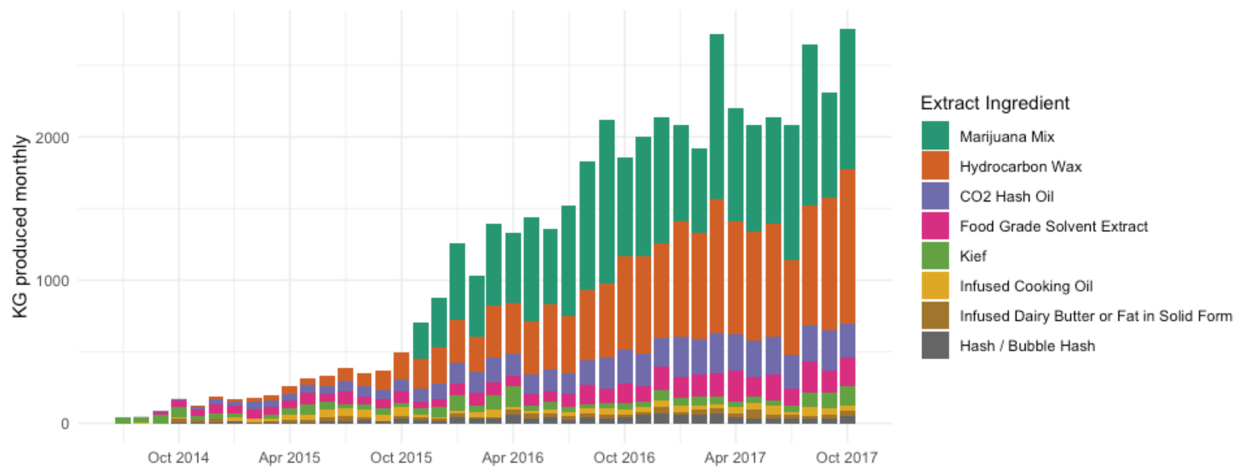


Table 2.9. Extract Ingredients: Production Volume (kg), Semiannual

Extract Ingredient	2014-2	2015-1	2015-2	2016-1	2016-2	2017-1	2017-2
Hydrocarbon wax	29	258	974	2,076	3,398	4,840	5,806
Marijuana mix	—	—	592	3,277	5,211	4,688	5,554
CO_2 hash oil	62	269	500	914	1,210	1,575	1,507
Food-grade solvent	170	369	388	491	728	979	1,136
Kief	279	225	250	482	250	294	733
Infused cooking oil	19	190	242	187	237	249	253
Infused butter/fat (solid)	70	80	124	132	163	227	181
Hash	4	26	86	127	187	177	160
Bubble hash	10	28	32	123	81	116	127

Table 2.10. Extract Ingredients: THC Produced (kg), Semiannual

Extract Ingredient	2014-2	2015-1	2015-2	2016-1	2016-2	2017-1	2017-2
Hydrocarbon wax	19.5	179.7	708.5	1,472.5	2,373.4	3,444.7	4,057.0
CO_2 hash oil	28.1	157.4	310.4	588.3	808.9	1,032.1	980.1
Marijuana mix	—	—	86.3	526.6	993.6	925.8	1,020.7
Food-grade solvent	55.4	192.7	197.9	269.7	417.2	603.9	725.6
Kief	51.3	70.2	91.7	172.7	102.6	122.5	260.3
Hash	2.2	9.5	36.8	78.5	115.1	104.0	91.7
Bubble hash	3.7	15.4	17.9	66.9	48.5	69.0	77.0
Infused cooking oil	0.9	9.7	5.6	43.5	29.4	25.0	13.5
Infused butter/fat (solid)	2.4	1.9	12.2	13.0	13.1	15.5	12.0

Table 2.11. Extract Ingredients: CBD Produced (kg), Semiannual

Extract Ingredient	2014-2	2015-1	2015-2	2016-1	2016-2	2017-1	2017-2
Hydrocarbon wax	0.6	8.0	22.2	66.9	107.3	134.8	125.9
CO_2 hash oil	1.7	8.6	20.9	54.3	68.8	107.6	116.9
Marijuana mix	—	—	3.6	20.7	37.4	26.2	22.3
Food-grade solvent	1.4	10.1	38.0	45.9	74.9	84.5	91.5
Kief	3.3	3.1	2.8	4.3	2.6	2.9	7.9
Hash	0.0	0.3	2.2	2.7	7.3	6.5	5.9
Bubble hash	0.2	0.5	0.5	4.8	3.6	2.9	1.6
Infused cooking oil	0.1	1.1	4.3	11.9	7.3	10.1	5.9
Infused butter/fat (solid)	0.0	0.2	0.5	0.4	0.7	0.2	0.0

Retail Products

Data on the production of retail products (which occurs before and regardless of whether they are later eventually sold by a retail store) is provided in Tables 2.12, 2.13, and 2.14. Table 2.12 counts the number of retail packages produced (dated at the time of production), separate of whether and when they are sold. The values in this Table 2.12 do not reflect the size of each product, e.g., whether a retail package of usable marijuana consists of one gram or seven grams. Table 2.13. provides the production volume in kilograms for the four products where this metric can be calculated. For example, Table 2.12 provided that an estimated 39,930,000 packages of usable marijuana were produced in 2016; Table 2.13 further documents that those packages contained an estimated 85 MT of usable marijuana (averaging 2.1 grams per package sold).

Table 2.12. Retail Items: Number of Retail Packages Produced (1,000s), by Year

Retail Product	2014	2015	2016	2017
Usable marijuana	1,844	18,445	39,930	52,048
Solid marijuana-infused edible	234	3,210	10,026	16,446
Liquid marijuana-infused edible	173	612	1,404	1,707
Marijuana extract for inhalation	170	2,488	8,739	15,121
Marijuana-infused topicals	4	178	412	621
Capsule	—	—	91	500
Marijuana mix infused	—	52	1,404	3,471
Marijuana mix package	—	306	1,355	1,802
Suppository	—	—	1	16
Tincture	—	—	32	83

Table 2.13. Retail Items: Production Volume (kg)

Year	Usable Marijuana	Extract for Inhalation[a]	Marijuana Mix Infused[b]	Marijuana Mix Package[b]
2014	3,023	—	—	—
2015	34,819	—	75	506
2016	85,000	6,610	1,327	2,349
2017	126,191	12,855	3,421	2,758

[a] Product weight not reported until July 2015; 2015 estimate only for July–December.
[b] Product category did not exist until July 2015; 2015 estimate only for July–December.

Missing data prevent comprehensive estimates of the weight of marijuana extracts for inhalation; prior to July 2015, the weight of these products was not reported. This affects estimates both of the weight of production volume (Table 2.13) and of total THC production (Table 2.14) for this product type. Table 2.14 provides estimates of the total weight of these products in kilograms.

Table 2.14. Weight of THC Produced Annually (kg)

Retail Product	2014	2015	2016	2017
Liquid edible[b]	12.2	39.5	98.4	119.9
Extract for inhalation[a]		951.7	4,098.7	8,300.9
Marijuana mix infused	—	22.9	384.1	1,148.9
Marijuana mix package	—	50.5	302.6	173.7
Solid edible[b]	16.5	137.2	491.0	972.5
Usable marijuana	485.0	6,666.4	16,557.2	25,959.2

[a] Product weight not reported until July 2015; 2015 estimate only for July–December.
[b] Estimated with analysis of label text.

Retail Sales

Data relating to the volume of retail sales are analyzed in this section. For all products, we may measure and report the number of individual packages sold at retail (Table 2.15) and the total sales value after excise tax (Table 2.17 and Figure 2.5). Data in these tables are forecasted for November and December 2017, following a method analogous to that used to forecast production volume (based on historical comparison with November and December 2016, as discussed previously).

Some products are also amenable to measurement by weight: dried flower (regardless of whether it is classified as usable marijuana or marijuana mix package), dried flower blended with hash or kief (marijuana mix infused), and products classified as marijuana extracts for inhalation (i.e., oils for vaporization, hash, and kief).[7] For these products, we report weight in kilograms (Table 2.16), referring to the weight of the product exclusive of any packaging. Much of the category "extracts for inhalation" pertains to oils contained inside of vaporizer cartridges. For these products, *usable weight* refers to the weight of the oil, not including the weight of the cartridge itself. For those products, it is more informative to measure the usable weight than the number of units; a single 1g cartridge of oil should not be considered the same as two 500-mg cartridges.

Figure 2.5. Retail Sales Revenue (Post-Excise Tax, Millions)

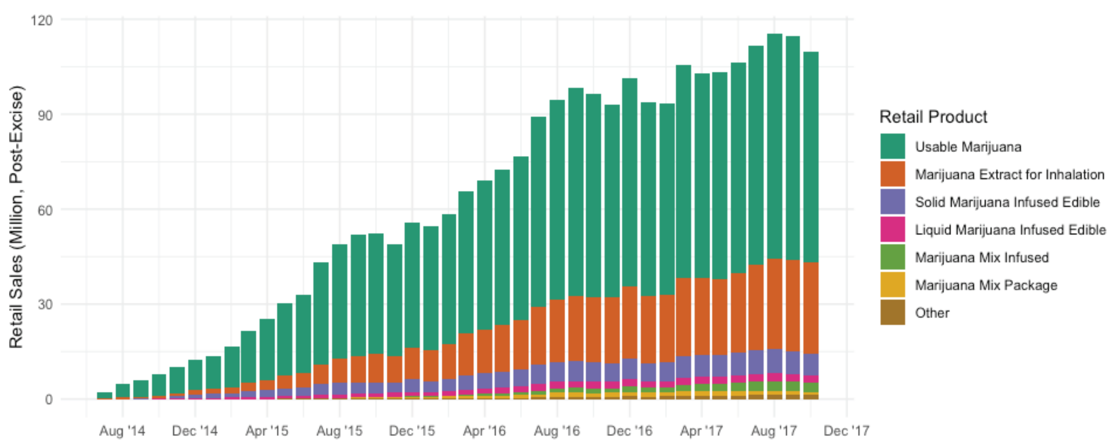


Table 2.15. Number of Retail Packages Sold at Retail (1,000s), by Year

Retail Product	2014	2015	2016	2017
Usable marijuana	755	12,076	30,273	43,995
Extract for inhalation	56	1,489	6,106	11,902
Solid edible	58	1,209	3,217	4,837
Marijuana mix infused	—	12	735	2,611
Marijuana mix package	—	126	908	1,658
Liquid edible	17	330	836	1,180
Marijuana-infused topicals	0	45	188	355
Capsule	—	—	3	165
Tincture	—	—	7	55
Suppository	—	—	0	2

[7] Other products are not amenable to measurement by weight in this fashion. For example, capsules and suppositories are near weightless; edibles pose different problems, e.g., for a marijuana-infused edible that takes the form of a brownie, it is of little interest whether the brownie weighs one ounce or four ounces.

Table 2.16. Weight of Flower-Based and Extract Products (kg) Sold, Annual

Retail Product	2014	2015	2016	2017
Usable marijuana	1,810	28,948	73,995	108,082
Extract for inhalation*	—	869	5,158	10,303
Marijuana mix package	—	269	1,929	2,781
Marijuana mix infused	—	34	821	2,623

* Product weight not reported until July 2015.

Table 2.17. Retail Sales Revenue ($1,000s, Post-Excise-Tax), Annual

Retail Product	2014	2015	2016	2017
Usable marijuana	36,141	326,708	652,424	801,331
Extract for inhalation	3,950	66,618	200,527	311,306
Solid edible	2,406	32,991	64,238	83,042
Liquid edible	822	11,651	22,915	27,675
Marijuana mix infused	-	274	11,137	30,176
Marijuana mix package	-	2,191	12,249	15,057
Marijuana-infused topicals	19	1,340	5,613	9,566
Capsule	-	-	62	2,929
Tincture	-	-	220	1,670
Suppository	-	-	14	47

The total weight of THC and CBD sold at retail may be estimated using methods analogous to those used to estimate THC and CBD produced, as discussed in Section 2.3. For products that are measurable by weight (i.e., usable marijuana, extract for inhalation, and marijuana mix infused and package), each product's reported weight in the retail table is multiplied by its reported THC and CBD content reported in the potency test associated with that product. For edibles, average THC content per solid or liquid edible is estimated using text analytic and machine learning methods (described in Section 2.3) and multiplied against the total number of those units reported to be sold. Table 2.18 provides semiannual estimates for the volume of THC sold at retail, including edibles but excluding topicals, tinctures, capsules, and suppositories; Table 2.19 provides similar estimates for the volume of CBD sold.

Chapter 4 compares these estimates of stores' sales of THC to Chapter 3's estimates of consumption by Washington residents. In particular, Chapter 4 uses the figure of 26 MT of THC sold during the period July 1st, 2016–June 30th, 2017, based on the rounded sum of Table 2.18's estimates of 11,213 kg of THC sold in the second half of 2016 and 14,387 kg sold in the first half of 2017.

Table 2.18. Weight of THC Sold at Retail (kg), Semiannual

Retail Product	2014-2	2015-1	2015-2	2016-1	2016-2	2017-1	2017-2
Usable marijuana	300	1,639	3,932	5,658	8,313	9,686	11,527
Extract for inhalation[a]	—	—	551	1,265	2,331	3,872	4,138
Marijuana mix infused	—	—	10	59	182	356	556
Marijuana mix package	—	—	49	109	255	326	263
Solid edible[b]	5	22	41	65	99	116	135
Liquid edible[b]	1	10	19	26	33	31	35
Total	306	1,671	4,602	7,182	11,213	14,387	16,654

[a] Product weight not reported until July 2015.
[b] Estimated with analysis of label text.

Table 2.19. Weight of CBD Sold at Retail (kg), Semiannual

Retail Product	2014-2	2015-1	2015-2	2016-1	2016-2	2017-1	2017-2
Usable marijuana	5.0	33.6	64.3	98.5	151.1	154.6	191.0
Extract for inhalation[a]	—	—	13.5	29.7	64.0	97.2	129.8
Marijuana mix infused	—	—	0.1	1.3	3.9	7.2	11.2
Marijuana mix package	—	—	0.7	1.7	4.6	6.2	5.8
Solid edible[b]							
Liquid edible[b]							

[a] Product weight not reported until July 2015.
-

3. Cannabis Use in Washington State

Estimates of the Number of Cannabis Users

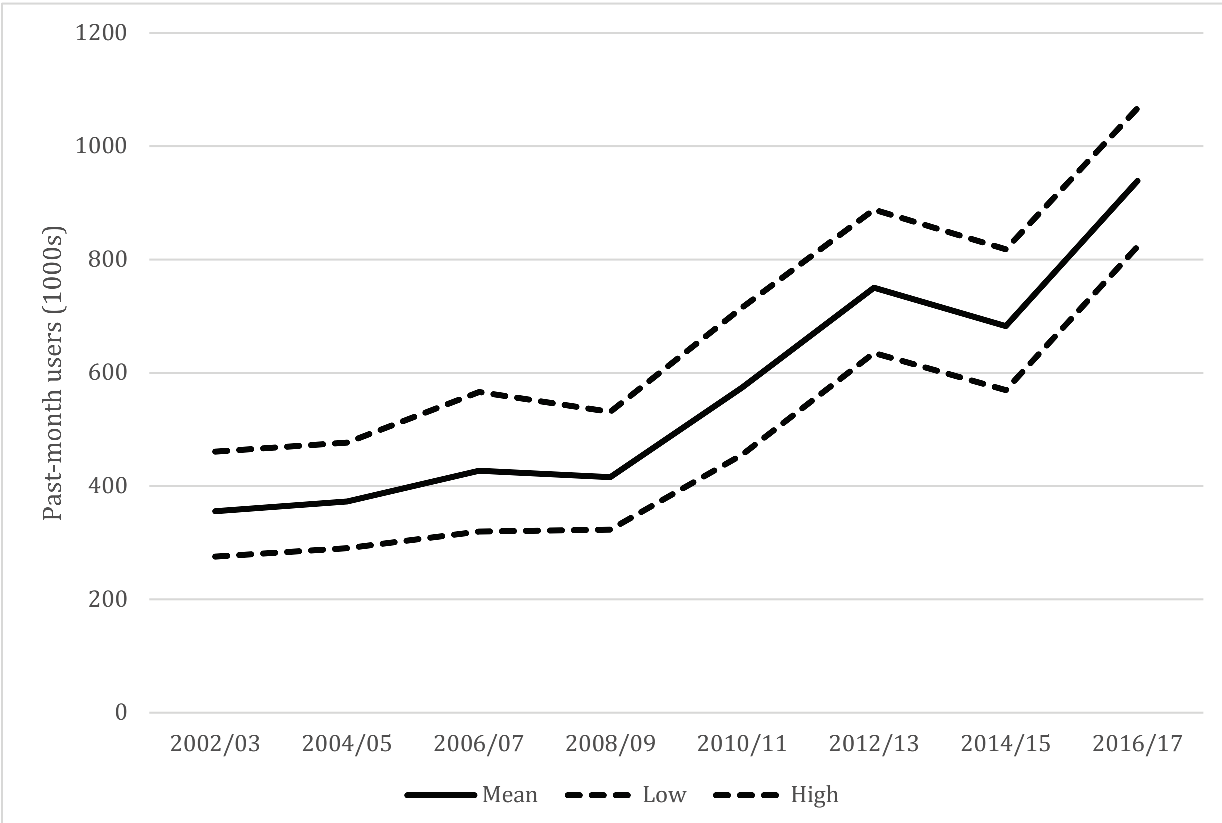
The NSDUH is a nationally representative survey of those ages 12 and older in the household population and homeless shelters. It does not cover the entire population; for example, it excludes certain active-duty military personnel. Nevertheless, it is the country's best source of information about numbers of cannabis consumers. The survey is conducted annually, but its state and substate estimates combine information from multiple years. In particular, state-level estimates are produced by combining surveys from adjacent years (e.g., 2015/2016, 2016/2017).

Unadjusted Estimates for 2016/2017

For this analysis, we obtained state-level estimates of cannabis use prevalence and cannabis use frequency (measured in days of use) through the NSDUH RDAS, an online tool hosted at the Substance Abuse and Mental Health Data Archive. Subject to certain confidentiality restrictions, the RDAS allows users to crosstabulate NSDUH data with state identifiers not provided in the public use dataset. The statistics available through RDAS (e.g., counts, standard errors, confidence intervals) are analysis-weighted to account for the complex survey design and to produce estimates representative of the average population across a given pooled two-year period (2002/2003, 2004/2005, 2006/2007, 2008/2009, 2010/2011, 2012/2013, and 2014/2015). The 2016/2017 data are from reports published by the Substance Abuse and Mental Health Services Administration (SAMHSA) in November 2018.

As of 2016/2017 in Washington State, approximately 940,000 individuals in the household population ages 12 and older (15.3 percent of the population 12 and older; 95-percent confidence interval [CI] = 13.4 percent, 17.4 percent) reported use of cannabis in the past month, more than double the number in 2002/2003. Figure 3.1 depicts how the number of past-month cannabis users in Washington has grown over time. There was a sharp increase after 2008/2009, the timing of which corresponds with the issuance of a memo establishing a federal policy of nonenforcement against medical cannabis patients (Ogden, 2009). This upward trend seems to have leveled off beginning in 2012/2013 but then increased again in 2016/2017.

Figure 3.1. Trends in the Number of Past-Month Cannabis Users in Washington, 2002/2003–2016/2017



NOTES: 2002/2003–2014/2015 estimates based on the variable for past month use (IRMJRC) from the NSDUH RDAS two-year pooled estimates for Washington State. (IRMJRC is the imputed marijuana-use recency variable.) The RDAS reports estimated counts rounded to the nearest thousand. The 2016/2017 data are from figures published by SAMHSA (2018).

Adjusting the NSDUH Estimates

We need to adjust the NSDUH figures upward to account for those excluded from the survey's sampling frame as well as for underreporting. Kilmer et al. (2013) identified four main adjustments, and Table 3.1 displays possible values for each factor. These factors were combined to generate a global adjustment of 1.22 with a standard deviation of 0.13.[8]

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[8] Kilmer et al. (2013) noted,

> A useful way to think about the combined effect of all four components is as the product of four uncertain numbers (i.e., four "random variables"). If the four uncertainties can be considered one at a time (i.e., are "independent"), then the expected value of the combined effect is just the product of each component's expected value: (1.018 + 1.06) / 2 x 1.0 x (1.0 + 1.35) / 2 x 1.0, or 1.22. But the issue of concern here is not just or mainly the "best guess" but, rather, what is a plausible range of values. If the second and fourth factors are seen as ranging from 0.9 to 1.1 but with 1.0 being the most likely value, then the combined effect of the four has a standard deviation of 0.13, with about 90-percent chance of falling between 1.02 and 1.43. That is, the second and fourth factors need to be recognized because they contribute to uncertainty in this factor, even if they are not believed to push it higher or lower, in expectation" (Appendix, p. 15).

Table 3.1. NSDUH adjustments made by Kilmer et al. (2013)

Adjustments	Possible Values
1. Use by people outside the NSDUH's sampling frame (e.g., active military, homeless who are not in shelters)	1.018–1.06
2. Use by people who are in the sampling frame but nonetheless are not surveyed (e.g., because they were never home or refused to take the survey)	Unknown; previous research suggests it could be greater or less than 1.0.
3. Misreporting of past-month use by people who are successfully surveyed	Perhaps in the range 1.0–1.35
4. Misreporting of quantities consumed (e.g., days used in the past month), even if some use is acknowledged.	Unknown; could be greater or less than 1.0.

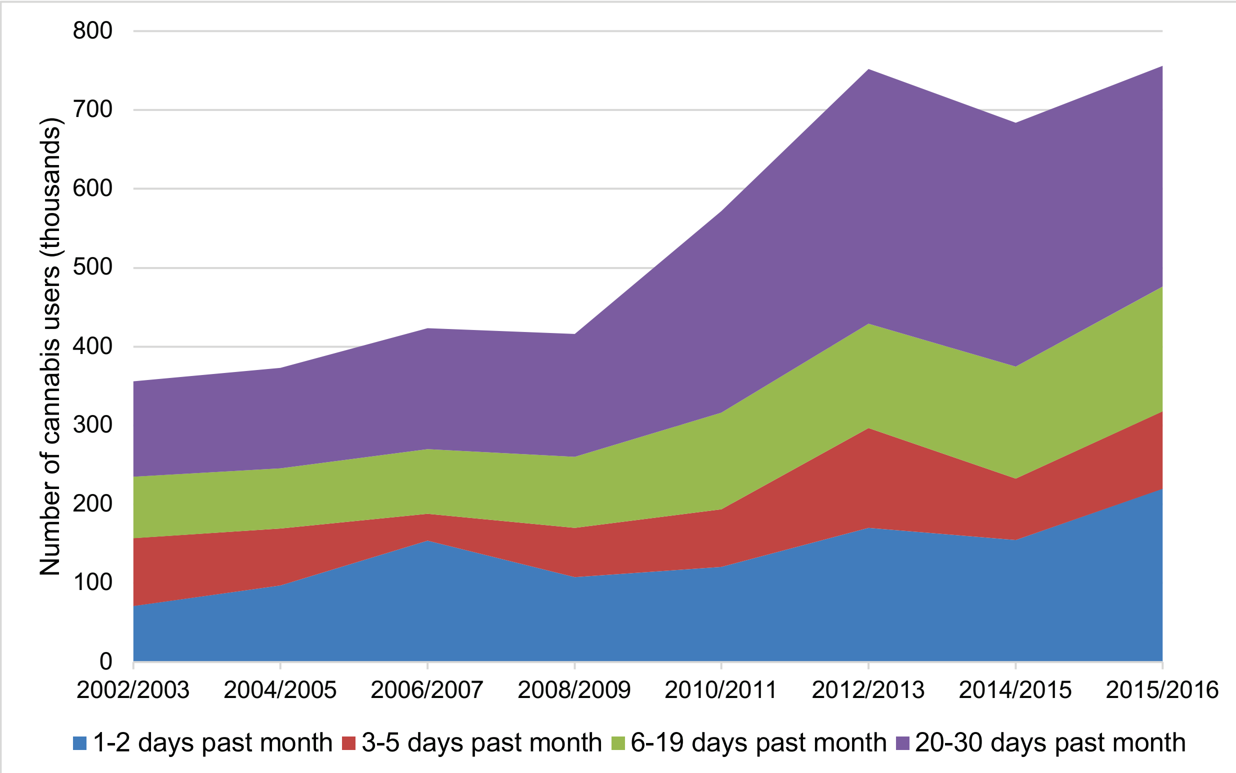
We have no reason to believe that the values for Adjustments 1, 2, and 4 have changed much over the past five years. Adjustment 3—misreporting by people who are successfully surveyed—could have changed if NSDUH respondents in Washington are now more likely to accurately report whether they use cannabis. On the one hand, the change may not be large. Cannabis possession had already been state-legal for Washington adults ages 21 and older since December 9, 2012 (and for those 18+ with a medical recommendation). Nor has federal law changed over this time; it is still illegal under federal law. Thus, some respondents may still not wish to report their use in a survey conducted by the federal government. For that matter, there is even underreporting of alcohol, so some adjustment will probably always be needed, even if the federal government also legalizes. On the other hand, over the course of the Obama administration, it became increasingly clear that the federal government was not going to crack down on legalization states (Cole, 2013); thus, those 2016/2017 NSDUH respondents in Washington may have been less likely to hide their use than those in earlier years. That might suggest reducing the upper bound on Adjustment 3; however, we do not have any evidence on which to justify the size of the reduction and do not think it would be a large change. Thus, for consistency with past estimates, we keep the same range we previously used but discuss the implications of this assumption in Chapter 4.

Estimating the Amount of Cannabis Consumed by User Type

Distribution of Use Days

Figure 3.2 shows trends in how past-month cannabis users are distributed in terms of days of past-month use. The frequency categories shown (1–2 days, 3–5 days, 6–19 days, and 20–30 days) reflect the classification scheme employed by NSDUH. In 2015/2016, more than one-third (37.1 percent) of past-month cannabis users in Washington reported cannabis use on at least 20 days in the past month. The distribution of past-month users who are in each use frequency category has remained roughly similar over time, although there has been a slight trend toward a more bimodal distribution, with the greatest growth in number of past-month cannabis users occurring in the 1–2 days and 20–30 days use categories.

Figure 3.2. Trends in the Number of Past-Month Cannabis Users in Washington, Categorized by Use Frequency



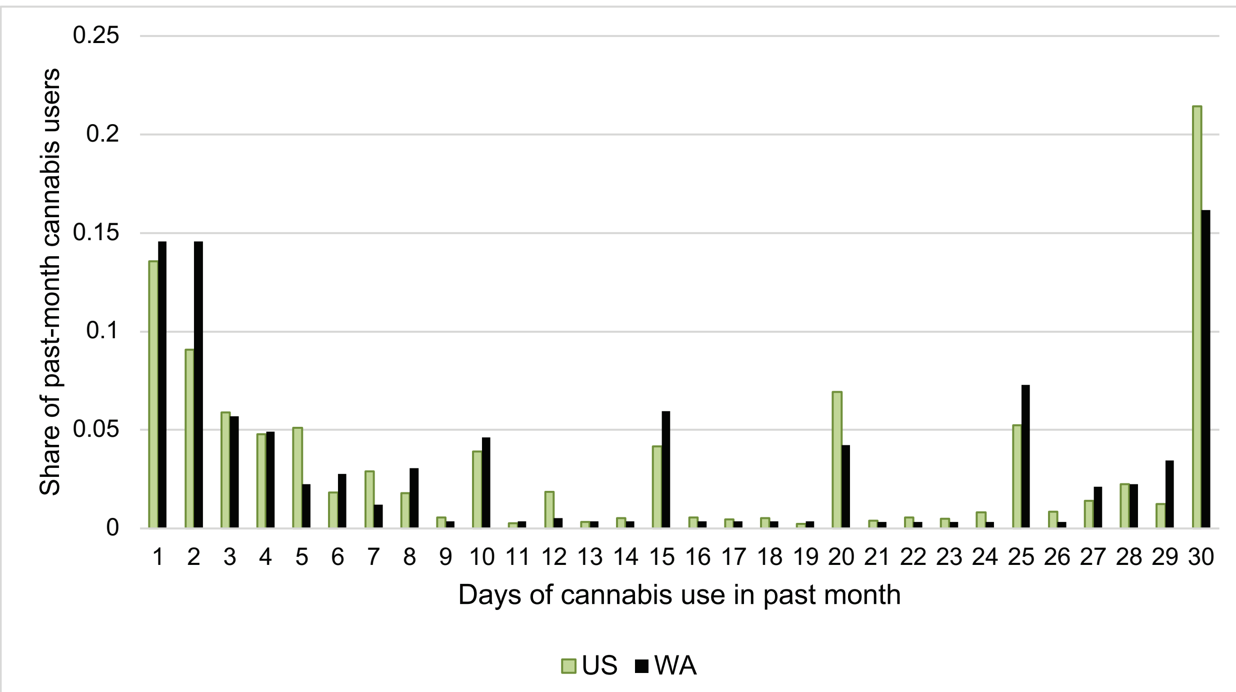
NOTES: Estimates based on the variable "MRJMDAYS" from the NSDUH RDAS two-year pooled estimates for Washington State. The RDAS reports only estimated counts rounded to the nearest thousand.

This bimodal distribution of use days is even more apparent when analyzing the distribution of use-days for each specific number of days, not in binned ranges, but that can be done fully only with national data. While NSDUH collects information from respondents on the exact number of use days in the past month (and in the past year), RDAS confidentiality restraints limit detailed reporting of the frequency of cannabis use. To maintain protections of personal information while obtaining the most-detailed estimates possible, we adopted a two-stage approach. First, we obtained estimates of the number of past-month users by days of use in the past month for all days of use that were not suppressed. Second, for days of use values that were reported rarely enough that their frequency estimates were suppressed in RDAS, we imputed the number of users by evenly distributing the unassigned number of users within that frequency category across the suppressed values.[9]

[9] For example, in 2015/2016, we can observe an estimated 280,000 respondents reported past-month marijuana use in the 20–30-day frequency category. When we tabulated outcomes by single day of use among this use frequency category, the RDAS provides the following breakdown: 32,000 (20 days), 55,000 (25 days), 16,000 (27 days), 17,000 (28 days), 26,000 (29 days), 122,000 (30 days), and suppressed values for 21 to 24 and 26 days of use. Based on the estimate by category, we reallocate the missing 12,000 respondents who reported past-month use of 20–30

Figure 3.3 graphs the share of past-month cannabis users with past-month use frequencies by day, comparing consumers in Washington with those in the United States overall. Several points are apparent from the figure. First, the distribution of cannabis users by days of use is largely U-shaped, with substantial mass concentrated in the tails of the distribution. Second, there is evidence of heaping or "digit bias" where respondents tend to favor reporting days of use in multiples of five; this phenomenon has been well-documented in other domains, including self-reported age (Myers, 1976), cigarette smoking (Wang and Heitjan, 2008), and household expenditures (Browning, Crossley, and Weber, 2003). Finally, in both Washington and the United States overall, the modal self-reported use pattern among past-month cannabis users is to consume cannabis daily.

Figure 3.3. Distribution of Number of Days of Cannabis Use in the Past Month Among Past-Month Users in Washington, 2015–2016



NOTES: Estimates calculated based on the variable IRMJFM from the NSDUH R-DAS two-year pooled 2015/2016 data. (IRMJFM is the imputed frequency of past-month marijuana use variable.)

Quantity of THC Consumed per Use Day

As noted in Chapter 2, more than one-third of cannabis expenditures in the state are attributable to nonflower products, with the fastest growing market segment being extracts for inhalation. However, to learn more about the patterns of cannabis consumption, we must look

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days [280,000 – (32,000 + 55,000 + 16,000 + 17,000 + 26,000 + 122,000) = 12,000] evenly across the days of use that contained suppressed values.

beyond the traceability data—especially since the traceability data do not cover consumption from cannabis that did not come from the licensed system. While the NSDUH might seem like an obvious starting point, information on products and amounts are not included in the RDAS system.

The 2016 Healthy Youth Survey asked students enrolled in public school about how they normally consumed cannabis. Of the 26 percent of 12th-graders who reported consuming in the past month, 74 percent reported that they usually smoked it, 14 percent usually ate it, 4 percent usually vaped, and the remaining 8 percent usually consumed other products (Healthy Youth Survey, 2016).

Similar to Kilmer et al. (2013), we fielded a web survey to learn more about cannabis consumption patterns in Washington. Although it was a convenience sample and not intended to be representative, it attracted a large number of heavy users—37 percent of past-month cannabis users in NSDUH and 73 percent of our survey respondents report more than 19 days of use—and their answers are of particular interest because the minority of users who use heavily account for the great bulk of consumption. Unlike in Kilmer et al. (2013), the 2018 survey of respondents tended to be older. Three-quarters of respondents in the 2018 survey reported they were 35 years of age or older, 15 percentage points higher than in the 2013 survey. See appendix Table A.6 for a comparison of past-month users in NSDUH, Kilmer et al. (2013), and our most recent survey.

We attribute these differences to the fact that the main promotion was done via the WSLCB email list sent to those who want more information about the legalization process. Posters promoting the survey were also emailed to retail establishments, although it is unclear whether they were actually posted. Other cannabis surveys (e.g., van Laar et al., 2013; European Monitoring Centre for Drugs and Drug Addiction, 2016) use Facebook and Instagram ads to promote and target certain populations, but when we attempted to do this, the company rejected multiple ads.

The survey asked respondents about which cannabis products they consumed in the past year. Table 3.2 displays the results for both the recent (2018) and previous (2013) surveys.[10] Flower was still the mostly popular product, at nearly 90 percent, but more than 60 percent of respondents reported consuming an edible, and more than 50 percent reported using an oil cartridge for a vape pen in the past year.

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[10] A comparison of respondent demographics for these web surveys and NSDUH are presented in appendix Table A.6.

Table 3.2. Share of Respondents Reporting the Use of Various Cannabis Products in Previous Year (percentage)

Product	2018 (*n* = 1,227)	2013 (*n* = 1,659)
Dried bud/flower/leaf (marijuana)	89.0	98.0
Hashish (resin)	32.4	50.9
Disposable vape pen	34.5	46.8
Oil cartridges for nondisposable vape pens	51.1	
Oil, but not in a vape pen	28.0	
Dabs/wax/budder/shatter	42.4	
Solid edibles (e.g., brownies or candy)	62.9	77.8
Teas or other beverages	23.3	22.6
Lotion/salve/balm/spray	40.8	23.5
Keif/kif/kief	36.8	44.7
Other (please specify)	8.9	5.8

Among daily or near-daily (DND) cannabis users in our survey who had consumed flower in the past week, the Winsorized mean for the amount used during a typical day was 1.58 g (standard deviation [s.d.] = 1.39). When shown pictures of either 0.5 g or 1 g of cannabis (picture randomly assigned; includes prompts) and asked if during their last use day they used exactly that amount, half that amount, less than half that amount, twice that amount, etc., the mean was 1.64 g (s.d. = 1.65).

Both of these estimates are close to the 1.6 g midpoint used in Kilmer et al. (2013). Thus, we keep the same distribution (lower = 1.3, middle = 1.6, upper = 1.9). Also similar to Kilmer et al. (2013), we assume a ratio of grams per day for DND versus once-per-month users that ranges from 2 to 3.

Estimating Cannabis Consumption in Washington State, FY 2017

The general approach for estimating the quantity of cannabis consumed in Washington in fiscal year 2017 follows that of Kilmer et al. (2013). A Monte Carlo simulation was used to explore how much uncertainty there is about an outcome when considering uncertainty in all the parameters simultaneously. In this section, we focus on *flower equivalent* consumption, which expresses nonflower use as a number of grams of flower that would contain roughly the same amount of THC. Table 3.3 describes the parameter values and distributions that serve as inputs to the Monte Carlo simulation.[11]

[11] Some assumptions embedded in this model are worth noting: Those who use on more days per month also tend to use more grams per day of use, and the relationship between number of days used per month and number of grams used per use day is proportional.

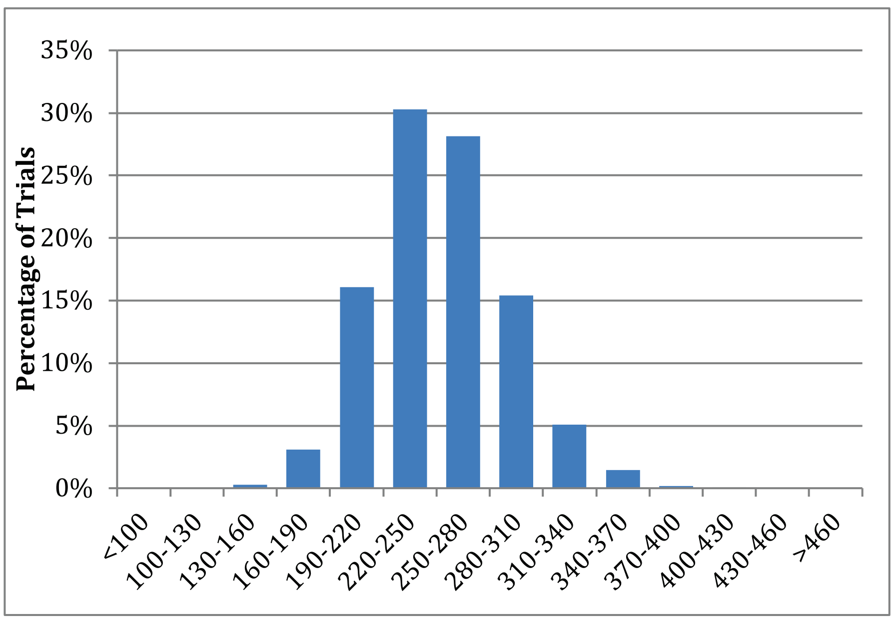
Table 3.3. Parameter Distributions and Data Sources Used in Estimation Demand Measures for Cannabis in Washington

Measure	Source	Distribution
Number of past-month cannabis users in Washington in 2015/2016	NSDUH RDAS	Normal (X, Y)
Past-month cannabis use days for Washington users in 2015/2016	NSDUH RDAS	Fixed, does not vary
Average grams of cannabis used per use day for daily users	Web survey	Triangular (1.3, 1.6, 1.9)
Ratio of grams per day for DND versus once-per-month users	Based on Kilmer et al., 2013	Uniform [2, 3]

NOTE: See text for clarification of sources and assumptions.

Figure 3.4 displays the flower equivalent of cannabis use by Washington residents in FY 2017. We estimate the mean amount to be 252 MT with a standard deviation of 37. The 10th and 90th percentile values are 206 MT and 301 MT, respectively.

Figure 3.4. Distribution of Cannabis Consumption Estimates for Washington Residents in FY 2017, Flower Equivalents (MT)



4. Comparing Sales and Demand Estimates

Our sales figures cover 2014 to 2017, but we estimated demand for only July 1, 2016, to June 30, 2017, the third year after recreational cannabis stores opened in Washington. Unlike Colorado, which allowed medical dispensaries to use existing stock to supply the nonmedical market when recreational stores opened, Washington started with an entirely new regulatory system, which was still ramping up production during the first few years of legal sales. Indeed, the amount of THC sold in Washington's legal stores in the second year was less than half of what was sold in the third year (Table 2.18). These points suggest a shortage in recreational cannabis supply in Washington from the program's implementation at least up to 2016.

Using data from Washington's traceability system, we estimate that approximately 26 MT of THC were sold in the licensed retail stores in Washington from July 1, 2016, through June 30, 2017 (see Table 2.18). About 18 MT was from flower, 6 MT was from extracts for inhalation, and the remaining 1–2 MT was from other products. The share of these sales attributable to non-Washington residents is currently unknown, but 10 percent might be one plausible guess.[12] Using this figure suggests that Washington residents ages 21 and older may have purchased approximately 23 MT of THC from licensed stores in Washington in FY 2017.

Comparing the sales data from stores with our estimates of total cannabis consumption by Washington residents requires a series of assumptions, some of which have little empirical justification. Given the significant uncertainty, our goal here is to produce a plausible range, not a precise point estimate, for the share of THC obtained by Washington residents that is provided by state-licensed stores. Indeed, to avoid giving a false sense of precision, we use round numbers. Additionally, in this section we generally refer to THC *obtained* instead of THC *consumed*, since the amount of THC absorbed in the bloodstream will depend on many factors, including the type of product being used.

These estimates require converting MTs of flower equivalents into MTs of THC. Our baseline estimate applies the same THC level used to make the conversion for the store sales: 20 percent. However, flower obtained from the illicit market may be of lower potency than what is sold in the stores. Indeed, the accompanying BOTEC report (Kleiman et al., 2019) suggests that licensed retailers are not very interested in selling flower with lower levels of THC. We also consider how lower values might influence the results.

[12] Estimates for Colorado suggest that 9 percent (19 of the 209 MT) of the cannabis consumed in Colorado in 2017 was by nonresidents (Orens et al., 2018), and Colorado may have more tourism than Washington. Data from the U.S. Travel Association suggest that in 2015, Colorado earned $3.3 billion in tax dollars from tourism, while Washington was closer to $2.5 billion (Burnett, 2017). Both states have many neighbors who may travel to the state just to purchase cannabis; however, Oregon's legal cannabis system was up and running by the beginning of FY 2017.

Table 4.1 displays various estimates of the share of THC obtained by Washington residents that comes from stores licensed by the WSLCB. Based on these scenarios, it seems plausible that within three years of creating a new regulatory system for cannabis, between 40 percent and 60 percent of THC obtained by Washington residents was through the state-legal market.

The first row gives the baseline estimate. It starts with the mean of the distribution of estimates shown in Figure 3.4 in flower equivalent weight (252 MT), rounded off to 250 MT to avoid creating an artificial sense of precision. That weight of flower equivalent is multiplied by 20 percent to generate an estimate of 50 MT of THC obtained by Washington residents ages 12 or older in FY 2017. If we assume that out-of-state residents accounted for 10 percent of the THC purchased in Washington's state-licensed stores, that would imply that the stores provided $26 \times 90\% = 23.4$ MT of THC to Washington residents, or 47 percent of THC obtained by Washington residents [$47\% = (26 \times 90\%)/50$].

Table 4.1. Various Estimates of the Share of THC Obtained by Washington Residents That Comes from WSLCB-Licensed stores, FY 2017

	(A) MT Flower Equivalents (rounded)	(B) Average THC Potency (%)	(C) Percentage of Store Sales from Non-WA Residents	(D) Percentage Supplied by WA's Legal Retailers
Use mean value from Figure 3.4	250	20	10	47
Use 10th percentile from Figure 3.4	200	20	10	59
Use 90th percentile from Figure 3.4	300	20	10	39
Focus on consumption only by those 21+	220	20	10	53
Assume 5% of store purchases from non-WA	250	20	5	49
Assume 15% of store purchases from non-WA	250	20	15	44
If flower from illicit supply was <20% and brought down state average to 18% THC	250	18	10	52
If flower from illicit supply was <20% and brought down state average to 16% THC	250	16	10	59
If we didn't make any adjustments to NSDUH	200	20	10	59

NOTES: Column D = $(26 \times (1–C)) / (A \times B)$. WA = Washington.

None of those parameters is known with certainty, so the remaining eight rows of Table 4.1 consider the implications of alternative values for several of these parameters. For example, Figure 3.4 displays a distribution of possible values for Washington residents' cannabis consumption. The mean of that distribution is 252 MT, but the 10th and 90th percentiles of that distribution are considerably lower and higher at 206 and 301 MT, respectively. Thus, rows 2 and 3 of Table 4.1 repeat the calculation of the proportion of Washington residents' THC that is supplied by Washington's state-licensed stores under the assumptions that their total cannabis consumption was 200 and 300 MT of flower equivalent. Naturally, if total consumption is lower (200 MT), then the amount of THC estimated to have been obtained by Washington residents from stores (23.4 MT) becomes a larger share of total THC consumption (59 percent). Conversely, if residents consumed more cannabis (300 MT), that would imply the THC supplied by state-licensed stores would account for a smaller share (39 percent) of consumption.

Stores are allowed to sell only to those 21 and older, so one might wonder what proportion of adults' THC consumption would have been supplied by stores if no store products indirectly made it into the hands of youth, and so youth obtained all of their cannabis from illegal markets. Based on our analyses of the 2015/2016 RDAS, we estimate that 87.7 percent of cannabis use days in Washington are by those ages 21 and older. If those under 21 consumed the same amount of THC per use day as those over 21, this would suggest that those 21 and older consumed approximately 220 MT in flower equivalents in FY2017. If *none* of the product purchased in stores was consumed by those under 21, this would suggest that 53 percent of the THC obtained by those 21 and older came from the stores (row 4).

Rows 5 through 8 vary the assumptions about the share of store purchases that are made by out-of-state residents and the average THC of all flower consumed in the state. The resulting figures all fall within the same 40 percent to 60 percent range.

As noted earlier, our NSDUH adjustment may be too high if respondents in Washington are now more likely to be honest about their cannabis use. If we take the extreme position and make no adjustment (i.e., ignoring all the factors listed in Table 3.1), the share of THC obtained in Washington coming from WSLCB-licensed stores is still slightly below 60 percent (row 9).

In sum, varying the assumptions as described alters the estimated proportion of THC that Washington residents obtained through WSLCB-licensed stores, but the proportions tend to remain between 40 percent and 60 percent.

5. Concluding Thoughts

Agencies regulating cannabis need good information about the size of their cannabis market and how it is changing. This can help them make informed decisions about several items ranging from licensing to revenue allocation to making projections about alternative tax regimes.

The analysis presented here for Washington State is similar enough to what was done previously (Kilmer et al., 2013) that it allows for crude comparisons over time in terms of flower equivalents. For 2013, our best estimate for total cannabis consumed by Washington residents was 175 MT (135–225). Our rounded FY 2017 estimate of 250 MT (200–300) is roughly 40-percent larger, but the wide and overlapping uncertainty bands surrounding these figures suggest that one should be careful about making strong claims about the precise magnitude of the increase.

This report contributes to the cannabis market literature by going beyond the standard measure of flower equivalents and addressing the amount of THC obtained. Using Washington's traceability system, we estimate that approximately 26 MT of THC were sold in the licensed retail stores in Washington from July 1, 2016, through June 30, 2017. About 18 MT were from flower, 6 MT from extracts for inhalation, and the remaining 1–2 MT from other products. This 26 MT is more than double the amount of THC sold in licensed stores in the previous year.

Estimating illegal markets' sales is always difficult, and it is more difficult for THC because data on the potency of cannabis products sold illegally are scarce. That also makes it difficult to know the *total* amount of THC obtained by residents from both legal and illegal sources combined. However, our best estimates suggest that within three years of the state's creating a new regulatory system, between 40 percent and 60 percent of THC obtained by Washington residents may have been obtained through the state-licensed stores. That likewise means that 40 percent to 60 percent of THC was *not* obtained through state-licensed stores, presumably meaning it came through the illicit market or from those authorized to grow for medicinal purposes.

Hence, one could say rather literally that our best guess is that the glass is both half-full and half-empty in terms of the state-licensed stores' ability to take market share away from the illegal market at the three-year mark; however, two important nuances should be borne in mind. First, sales in state-licensed stores grew much faster from year 2 to year 3 than did total THC consumption, so the state-licensed stores' market share was considerably higher in year 3 than it was in year 2, let alone year 1. Such increases could continue; a roughly 50/50 split at year 3 does not imply that state-licensed stores won't achieve a greater market share as time goes on.

On the other hand, since Washington residents' total THC consumption appeared to grow, progress at shrinking the illegal markets' volume is smaller than these proportions might suggest. For example, if total THC consumption grew by 40 percent over a period when the illegal markets' share fell from 100 percent to 50 percent, then the volume of THC supplied by illegal markets would still be 70 percent of what it had been (i.e., the decline in THC sold illegally would be just 30 percent, not 50 percent).

That said, part of the concern about illegal markets pertains to the revenues and profits that they produce for criminals, not the volume of goods sold *per se*. Prices in the state-licensed stores fell sharply over this time (Smart et al., 2017; Caulkins et al., 2018). Less is known about what happened to (potency adjusted) cannabis prices in illegal markets. If those prices fell by even two-sevenths (28.6 percent) and the illegal market was supplying 70 percent as much THC, then the illegal markets' revenues from those sales would still have fallen by a full 50 percent.

The preceding paragraphs pertained to the illegal market supplying sales in Washington State or, more precisely, to Washington residents. There may also be illegal production that occurs within Washington State borders but for export and sale in illegal markets in other states. This report does not estimate that activity because it would not show up in any of the datasets examined here; it would also be hard to determine. Advances in satellite technology (see, e.g., Butsic and Brenner, 2016) could improve detection of outdoor unlicensed cannabis farms, but not all production is outdoors, and variation in yield per acre under cultivation might be hard to track.

There is a variety of related questions that could be pursued in future analyses. One is *why* some Washington residents still obtain cannabis products through illicit channels. It is useful to know how much cannabis is obtained in one way or another, but if the goal is to bring the remaining consumers into the state-licensed supply system, it might be useful to interview them to better understand what it might take to get them to convert to legal channels. Conversely, it would be useful to know what share of legal sales are to nonresidents, and how many of them might be lost over time if other states establish state-licensed sources.

The analysis here pertained to THC obtained (purchased). However, different ways of consuming cannabis (smoking, dabbing, vaping, eating) vary in terms of the proportion and timing of THC that reaches users' bloodstreams and brains (Huestis, 2007). For example, when cannabis is smoked, some THC is lost to side stream smoke. That means that trends in THC consumption (meaning amounts ingested) and effective consumption (meaning amounts reaching the brain) could depart somewhat from trends in amounts obtained if products that are particularly efficient at delivering THC gain or lose market share. Tracking trends in THC consumption might be of greater relevance to those studying public health outcomes.

Finally, by making its traceability system publicly available, the state of Washington has made it much easier for analysts to address critical questions related to cannabis policy and the economics of cannabis (see, e.g., Smart et al., 2017; Hansen, Miller, and Weber, 2018). We hope other states follow Washington's lead by making some—if not all—of their transaction-level data available for research purposes.

Appendix

Table A1. Glossary of Cannabis Product Types

Name	Place in Supply Chain	Description
Flower	Plant material	Material harvested from the flower of the cannabis plant, where THC content is highest
OPM	Plant material	Material harvested from less potent parts of the cannabis plant, e.g., leaves and stalks
Marijuana mix	Ingredient	Combinations of bulk dried flower and/or OPM. Used to produce any retail product except for usable marijuana
Hydrocarbon wax	Ingredient	Cannabinoid concentrate extracted using hydrocarbons, e.g., butane hash oil
CO_2 hash oil	Ingredient	Cannabinoid concentrate extracted using pressurized carbon dioxide
Bubble hash	Ingredient	A variant of hash in which resin glands are separated from the cannabis plant using cold water
Kief	Ingredient	A type of concentrate that consists of resin glands containing cannabinoids and terpenes, with a loose powdery texture
Hash	Ingredient	A type of concentrate made from pressing and heating kief
Usable marijuana	Retail	Dried cannabis flower, i.e., "bud"
Marijuana mix package	Retail	Produced from marijuana mix, sometimes also mixed with flower. Colloquially known as “shake.”
Solid marijuana-infused edible	Retail	Solid edibles with THC or CBD content, e.g., brownies, chocolate bars, candy
Liquid marijuana-infused edible	Retail	Liquid edibles with THC or CBD content, e.g., sodas
Topical	Retail	Cannabis-infused lotions, balms, and oils that are applied and absorbed through the skin
Extracts for inhalation	Retail	Includes both solid cannabinoid concentrates of varying consistencies and textures (e.g., “wax,” “crumble,” “shatter”) and oil-based concentrates. Oil-based concentrates are generally packed either as a cartridge intended for use with a vaporizer pen or sold in droppers, e.g., “Phoenix Tears” or “Rick Simpson’s Oil.”
Capsule	Retail	Cannabinoid concentrate packaged in a pill

Table A2. Standard Deviation of Total THC Concentration, by Product, Year

Product Type	2014	2015	2016	2017
Bubble Hash	21.44	20.94	20.60	22.30
CO2 Hash Oil	17.67	19.46	21.39	23.08
Food Grade Solvent Extract	31.38	29.87	28.72	29.31
Hash	23.27	23.27	23.47	26.67
Hydrocarbon Wax	26.11	21.32	19.31	19.96
Infused Cooking Oil	1.88	6.75	22.94	16.57
Infused Dairy Butter or Fat in Solid Form	5.17	8.85	7.37	6.54
Kief	16.51	15.32	17.85	18.24
Marijuana Mix	NA	7.88	9.14	8.51
Marijuana Extract for Inhalation	21.44	19.51	26.50	26.45
Marijuana Mix Infused	NA	14.13	12.63	13.66
Marijuana Mix Package	NA	7.52	8.97	2.55
Usable Marijuana	6.87	6.11	6.74	7.54

Table A3. Standard Deviation of Total CBD Concentration, by Product, Year

Product Type	2014	2015	2016	2017
Bubble Hash	0.67	2.47	7.48	5.29
CO2 Hash Oil	8.00	7.73	10.29	12.64
Food Grade Solvent Extract	0.79	15.91	17.36	16.84
Hash	0.57	4.72	7.44	7.96
Hydrocarbon Wax	2.35	6.17	8.62	7.83
Infused Cooking Oil	0.07	1.30	3.49	14.76
Infused Dairy Butter or Fat in Solid Form	0.16	0.43	0.78	0.15
Kief	2.25	2.49	2.12	1.80
Marijuana Mix	NA	1.07	1.72	1.26
Marijuana Extract for Inhalation	2.87	6.65	10.61	13.53
Marijuana Mix Infused	NA	2.56	1.47	2.37
Marijuana Mix Package	NA	0.16	0.53	0.68
Usable Marijuana	1.56	1.74	1.87	1.54

Table A4. Estimated Share of THC Produced That Is Sold

Year	Percentage Sold
2014	62.5
2015	69.8
2016	85.9
2017	87.9

Table A5. Estimated Share of THC Produced in Retail Products That Is Sold

Year	Liquid Marijuana-Infused Edible	Marijuana Extract for Inhalation	Marijuana Mix Infused	Marijuana Mix Package	Solid Marijuana-Infused Edible	Usable Marijuana
2014	33.8	—	—	—	28.8	62.5
2015	100.7	68.3	46.4	64.3	47.5	82.8
2016	61.1	88.8	60.9	120.7	36.0	84.7
2017	52.6	98.1	80.9	99.3	25.5	81.8

Table A6. Comparison of Washington Residents Reporting Past-Month Cannabis Use in NSDUH 2015/2016, Kilmer et al., 2013, and the Present Survey

Year	NSDUH 2015/2016	CCS 2013 (Kilmer et al., 2013)	CCS 2018
Percentage female	47.8	25.3	35.1
Percentage age > 34	49.4	57.1	75.0
Percentage white, not Hispanic	71.2	83.2	82.0
Percentage black, not Hispanic	4.5	0.6	0.9
Percentage other or multiple, not Hispanic	14.1	8.5	9.4
Percentage Hispanic	10.3	4.2	3.8
Percentage > 19 past-month use days	37.2	61.4	73.2

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