

Missouri's Medical Marijuana Market:
An Economic Analysis of Consumers, Producers, and Sellers

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Executive Summary

With the November 2018 election, medical marijuana became legal in Missouri. The purpose of this report is to assist Missouri's Department of Health and Senior Services with quantitative analyses of the market for medical marijuana. Specifically, we are charged with projecting the number of qualified patients and caregivers and the quantity of medical marijuana that will be needed to treat these patients. In doing so, we will use data from as many states as we can to identify market developments. In addition, it is critical that the key challenges facing Missouri regulators be brought forward—in particular the coexistence of the legal medical market and the illegal recreational market—so that best practices can be developed to help the legal market operate in the way in which it was intended. Overall, price and quantity provided in a timely manner are critical for the medical marijuana market to be as efficient as possible.

Our key findings are presented in the following bullet points:

- Medical marijuana markets have now existed in the U.S. since 1996 (California), growing to 33 states and the District of Columbia as of 2018. However reliable, quality data capture seemed an afterthought. In our view, Washington, Arizona, Massachusetts, and Colorado offer the most complete data available and we rely principally on these four states for our calculations. We observe that the market for medical marijuana grows over the first several years, reflecting a maturation process.
- Based on evidence from across 19 states and over time, we project that the number of Missouri qualified patients will be approximately 19,000 in 2020, 22,500 in 2021, and 26,000 in 2022.
- Based on consumption per medical marijuana patient, we project with 66 percent confidence that Missouri cultivators will need to harvest between 5,000 pounds and 7,000 pounds for the approximately 19,000 qualified patients in year 2020.
- Based on the average production and the distribution of growers—indoor and outdoor—in Colorado, we project with 66 percent confidence that Missouri will need between 10 and 14 cultivators in 2020, 18 to 24 cultivators in 2021, and 24 to 29 cultivators in 2022.
- Based on the growth of qualified patients over time, we project that Missouri will support 85 infused-product manufacturers, perhaps in the first year of medical marijuana sales. There is no data reported on the output of the typical infused-product manufacturers. Because the projection is based exclusively on Colorado reports, the confidence in the projection is low.
- Based on quantity of medical marijuana sold per dispensary in Washington and in Colorado, we project with 66 percent confidence that between 115 and 132 dispensaries will be needed by the year 2022.

- Both price and quantity reports are critical for regulators to properly monitor developments in the medical marijuana market and to limit opportunities for legal medical marijuana to be diverted to the illegal recreational market.
- There are a number of actions already undertaken to address the potential diversion from the legal medical market to the illegal recreational market. Specifically, the application fees for participants in the supply chain—that is, cultivators, infused-product manufacturers, and dispensaries—are large enough to incentivize firms to abide by the law. In addition, the seed-to-sale technology is an important monitoring feature to deal with the potential moral hazard in the legal medical marijuana market.
- Our chief recommendation is that monitoring also include a functioning real time reporting mechanism that looks at both price and quantity movements, especially at the cultivator and dispensary levels. The Department of Health and Senior Services has indicated that they have real-time data on price and quantity, so the signs are encouraging that diversion to illegal markets can be minimized.

1. Introduction

On November 6, 2018, Missouri voters approved Amendment 2, permitting state-licensed physicians to recommend marijuana for medical purposes to patients with serious illnesses and medical conditions. Hereafter Amendment 2 will be referred to as the Medical Marijuana Amendment, MMA for short. Because no market existed previously for medical marijuana, the rules and regulations must be established and the market infrastructure needed to supply consumers must be built. Missouri's Department of Health and Senior Services is responsible for overseeing the market structure that meets the legally stipulated demand for medical marijuana.

In this report, our goal is to provide economic analysis that will form the basis for the market infrastructure that yields a stable price and quantity combination. In order to conduct these analyses, we need to review what the MMA stipulates and to carefully review the evidence that projects the demand for the medical marijuana. In other words, subject to the legal framework dictated by the MMA, we want to project the demand for medical marijuana and then make recommendations on the market infrastructure that will deliver the product to patients in the most stable setting.

We begin with a quick review of the key features of the MMA. In this review, we begin with a list of the restrictions stipulated in the amendment.

First, MMA specifies who is legally allowed to apply for medical use. The process begins with a licensed physician offering a professional opinion—that is, a physician certification—that a patient suffers from a qualifying medical condition. The set of qualifying medical conditions is:

- Cancer;
- Epilepsy;
- Glaucoma;
- Intractable migraines unresponsive to other treatments;
- A chronic medical condition that causes severe, persistent pain or persistent muscle spasms, including but not limited to those associated with multiple sclerosis, seizures, Parkinson's disease, and Tourette's syndrome;
- Debilitating psychiatric disorders, including but not limited to post-traumatic stress disorder, if diagnosed by a state-licensed physician;
- Human immunodeficiency virus or acquired immune deficiency syndrome (commonly known as HIV/AIDS);
- A chronic medical condition that is normally treated with a prescription medication that could lead to physical or psychological dependence, when a physician determines that medical use of marijuana could be effective in treating that condition and would serve as a safer alternative to the prescription medication;
- Any terminal illness;
- In the professional judgment of a physician, any other chronic, debilitating or other medical condition, including but not limited to hepatitis C, amyotrophic lateral sclerosis,

inflammatory bowel disease, Crohn’s disease, Huntington’s disease, autism, neuropathies, sickle cell anemia, and cachexia.

While these medical conditions comprise the list of qualifying conditions, we observe that the majority of cardholding patients in other states identify chronic pain as at least one of the conditions for which they are seeking medical marijuana as a treatment.

An important step is to quantify the amount of medical marijuana demanded by people in Missouri. One way to approach the expected demand would be to identify the incidence of each type of medical condition and then multiply that by the typical dosage for every disease. While some of the diagnoses are quite straightforward, others are more difficult, and some, like chronic pain, are not identified by the Center for Disease Control (CDC) as a disease. Consequently, valid diagnoses cannot be projected by using CDC incidence rates. We will, therefore, need some other approach to make projections about the number of qualified patients and the quantity of medical marijuana needed to meet the needs of these qualified patients in Missouri.¹

The Medical Marijuana Amendment also lays out the supply chain for medical marijuana in Missouri. Formally, the supply chain is divided among cultivators, manufacturers of marijuana-infused products, and dispensary facilities. The Department of Health and Senior Services is accountable for implementing the key licensing, certifying, and administering of the laws applicable to the business operators in the medical marijuana supply chain. In addition, the identification cards issued to qualified patients or to their primary caregivers are also under the administration of the Department of Health and Senior Services. There is a \$25 annual fee for qualifying patients and primary caregivers. The fee is indexed to the Consumer Price Index for all subsequent years. In addition, qualified patients and primary caregivers will pay an additional four percent tax on all retail sales of medical marijuana.

Key aspects of the Medical Marijuana Amendment that apply to the supply chain are:

1. A seed-to-sale tracking system that can be used to follow the production process from seed to harvest to infused-product manufacturer or dispensary and to a buyer possessing a valid Medical Marijuana I.D. card;

¹ Note that throughout this report, we will use the term “qualified patients” in an inclusive manner. Formally, MMA requires qualifying patients be a Missouri resident with at least one qualifying condition. For those qualifying patients, the next step is to apply for a card. Anyone 18 years and older can apply for a card. It is also possible for a primary caregiver who is at least 21 years old to be designated as the cardholder for the qualifying patient. In this paper, we use the term qualified patient to include qualifying patients at least 18 years old. If you require a Primary Caregiver, that person must be at least 21 years of age and must be designated on your application for a Medical Marijuana Identification Card. On July 4, 2019, or after, the State of Missouri will begin accepting applications for Medical Marijuana I.D. cards. The application fee is \$25 for the qualifying patient. A Primary Caregiver must also pay a separate \$25 fee. Upon receipt of the Medical Marijuana I.D. card, the qualified patient or the Primary Caregiver can purchase medical marijuana from a state licensed dispensary.

2. Create and issue standards on the secure transportation of marijuana and marijuana-infused products;
3. Cultivators are divided among indoor, outdoor and greenhouse types, with indoor facilities limited to 30,000 square feet of flowering canopy space, outdoor facilities limited to 2,800 flowering plants, and greenhouse facilities limited to 2,800 flowering plants or 30,000 square feet of flowering canopy;
4. Each medical marijuana cultivating facility is charged a non-refundable fee of \$10,000 per application for a 3-year license and a non-refundable fee of \$5,000 per license renewal. Once granted, the licensee is charged an annual fee of \$25,000;
5. Each medical marijuana-infused manufacturing facility is charged a non-refundable fee of \$6,000 for a 3-year license and a non-refundable fee of \$3,000 per license renewal. Once granted, each licensee is charged a \$10,000 annual fee;
6. Each medical marijuana dispensary facility is charged a non-refundable fee of \$6,000 for a 3-year license and a non-refundable fee of \$3,000 per license renewal. Once granted, each licensee is charged a \$10,000 annual fee;
7. The aggregate number of licenses can be restricted by the Department of Health and Senior Services, but the restrictions cannot be less than:
 - One per 100,000 inhabitants is the fewest number of medical marijuana cultivator licenses that can be implemented by the Department of Health and Senior Services;
 - one per 75,000 inhabitants is the fewest number of medical marijuana-infused manufacturing facilities that can be implemented by the Department of Health and Senior Services;
 - 24 per U.S. congressional districts is the fewest number of medical marijuana dispensary facilities that can be implemented by the Department of Health and Senior Services.

In this report, a necessary step is to project the number of qualified patients and the projected consumption per qualified patient. The combination of people and consumption per person gives us a projected measure of the size of Missouri’s medical marijuana market. In particular, what is the expected quantity of medical marijuana in Missouri? From the bullet points above characterizing the MMA conditions, the reader can see the specific provisions that affect the market for medical marijuana. In addition, it will be useful to quantify the distribution of medical marijuana needs across the State of Missouri precisely because MMA specifies minimum lower bounds, or floors, for the number of dispensaries by Congressional district.

In this report, we begin by looking at patterns of market development as recorded in other states in which medical marijuana is legal. Section 2 presents a brief overview of the legal developments across states and the reports offered by those states. Based on the available data, the next step is to quantify the demand for medical marijuana in Missouri in Section 3. In addition, use the projected consumption to propose the supply chain for the Missouri market. In particular, how many cultivators, manufacturers, and dispensaries are projected to be needed to meet the projected quantity demanded? In Section 4, we present

an overview of the risks and information problems that will be present in the medical marijuana market. There are standard errors of the projections that exist because of frictions in the market, especially because there is the continuation of illegal recreation market; in other words, there is always an arbitrage opportunity for excess inventories that could syphon off legal medical marijuana into the illegal recreational market. Section 5 presents a brief summary and conclusions of the report.

2. Data

In this section, we review some of the key pieces of data collected from states that have already passed medical marijuana laws. There is a pattern emerging across states. States are currently divided between medical-use only and combined medical- and recreational-use.² Indeed, the evolution is consistent; that is, there is a kind of trial period in that every state that has passed laws allowing for recreational purchases had previously allowed for medical-use only.

There are presently 33 states and the District of Columbia with laws allowing for medical marijuana usage. In addition, ten states and the District of Columbia have laws that allow for marijuana to be used for recreational purposes. The states in which medical marijuana exist are presented in Table 1. The star is used to further identify those states in which recreational marijuana use is legal.

Table 1

States with Legal Medical Marijuana, February 2019

State	Medical Marijuana Passed
1. Alaska*	Medical: Measure 8 (1998), Senate Bill 94 (1999) Recreational: Measure 2 (2014)
2. Arizona	Proposition 203 (2010)
3. Arkansas	Issue 6 (2016)
4. California*	Medical: Proposition 215 (1996) Recreational: Proposition 64 (2016)
5. Colorado*	Medical: Amendment 20 (2000) Recreational: Amendment 64 (2012)
6. Connecticut	HB 5389 (2012)
7. Delaware	SB 17 (2011)

² Often, recreational use is referred to as adult-use marijuana across states. Throughout this report, the term “recreational use” refers to the legal market for marijuana sold to consumers of legal age.

8. Florida	Amendment 2 (2016)
9. Hawaii	Act 228 (2000)
10. Illinois	HB 1 (2013)
11. Louisiana	HB 149 (2015)
12. Maine*	Medical: Question 2 (1999) Recreational: Question 1 (2016)
13. Maryland	HB 1101 (2013)
14. Massachusetts*	Medical: Question 3 (2012) Recreational: Question 4 (2016)
15. Michigan*	Medical: Proposal 1 (2008) Recreational: Proposal 18-1 (2018)
16. Minnesota	SF 2471 (2014)
17. Missouri	Amendment 2 (2018)
18. Montana	Initiative 148 (2004)
19. Nevada*	Medical: Question 9 (2000) Recreational: Question 2 (2016)
20. New Hampshire	HB 573 (2013)
21. New Jersey	SB 119 (2010)
22. New Mexico	SB 523 (2007)
23. New York	A6357 (2014)
24. North Dakota	Measure 5 (2016)
25. Ohio	HB 523 (2016)
26. Oklahoma	State Question 788 (2018)
27. Oregon*	Medical: Ballot Measure 67 (1998) Recreational: Measure 91 (2014)
28. Pennsylvania	SB 3 (2016)
29. Rhode Island	SB 791 (2006)
30. Utah	Proposition 2 (2018)
31. Vermont*	Medical: SB 76 (2004) Recreational: H.511 (2018)
32. Washington*	Initiative 692 (1998) Recreational: Initiative 502 (2012)

33. West Virginia	SB 386 (2017)
34. Washington, D.C.*	Medical: Initiative 59 (1998) Recreational: Initiative 71 (2014)

Table 1 tells us that 34 of the 51 state and district political subdivisions in the United States have laws stipulating that medical marijuana is legal for a set of specified conditions. The table further shows that eleven of those political subdivisions have legalized marijuana for adult, recreational use after a trial period in which only medical marijuana is legal. California passed the first state legislation allowing medical marijuana use in 1996. A total of eleven states passed medical marijuana legislation before 2005. Between 2005 and 2015, thirteen additional states passed medical marijuana legislation. With respect to passing medical marijuana laws, the pace accelerated with ten states passing laws between 2015 and 2018.

As we look at medical marijuana across states, there is a pattern that is clear. The distinction between legal medical marijuana and illegal recreational marijuana requires some kind of identification process. Indeed, one common element is the means of implementing this distinction. In states that have passed laws allowing for medical marijuana usage, some form of registration is required. The rules specify a set of qualifying conditions, followed by a physician’s assessment verifying the condition. Together, these two steps identify a qualifying patient, which is then followed by a state governing authority issuing a card. At the card stage, a person is identified as a qualified patient. There is frequently a distinction between a qualified (adult) patient and a primary caregiver who is the responsible party for a qualifying minor (under age 18) patient. It is the governing state authority, which is the Department of Health and Senior Services in Missouri, that determines who is granted the identification card.

With the approved identification card, the qualified patient presents the card whenever purchasing medical marijuana from a state-licensed dispensary. Table 2 provides data on the fees that qualifying patients are charged to obtain the identification card for 15 states. As the reader sees, there is some variation across states. Minnesota, for example, has the highest application fee, charging \$200 for a qualifying patient. Arizona, Connecticut, Illinois, and New Jersey are the other states with fees of \$100 or more. Interestingly, Rhode Island charges a separate \$100 fee for primary caregivers. In many states, the application process is free. The cards are valid for one or two years. By MMA, qualifying patients must pay a \$25 application fee in Missouri in order to acquire a Medical Marijuana I.D. card. A primary

caregiver must also apply, paying \$25 to apply, and can be designated for up to three patients. Patients may have up to six flowering plants if they pay \$100 for a patient cultivation card.³

The intuition for having a fee is that the qualified patient will have some means of documenting their participation in the medical marijuana program. As we will discuss later in this report, there is an interesting margin that operates in states with a legal medical marijuana market and an illegal recreational

Table 2

Qualification Parameters for Medical Marijuana Usage

State	Caregiver fee (separate from application fee)	Application Fee (per year unless otherwise noted)	Renewal
Arizona		\$150.00	Annually
Arkansas		\$50.00	Annually
Colorado		\$25.00	Annually
Connecticut		\$100.00	Annually
Hawaii		\$38.50	Annually
Illinois		\$100.00	Most Annually
Michigan	\$25.00	\$60.00	biannually
Minnesota		\$200.00	Annually
Montana	N/A	\$30.00	Most annually
Nevada		\$50.00	Annually or Biannually
New Jersey		\$100.00	biannually
New York		\$50 but currently waived	
Pennsylvania		\$50.00	annually
Rhode Island	\$100.00	\$50.00	annually
Washington		\$95 (\$90 for renewal)	annually

³ There are additional restrictions on qualified patients with a patient cultivation card. See <https://health.mo.gov/safety/medical-marijuana/index.php> for draft rules and regulations on patients growing their own medical marijuana.

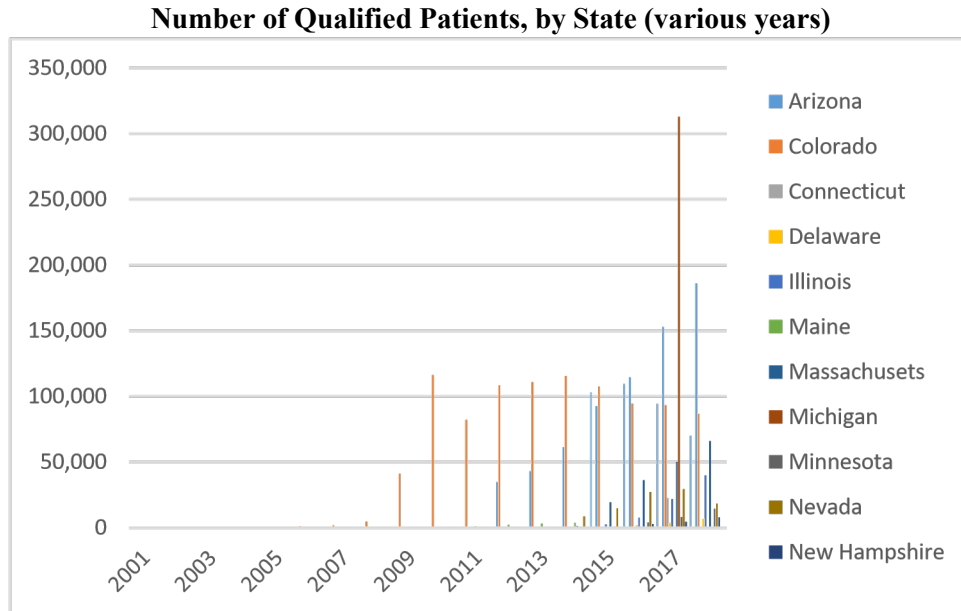
market. Specifically, application fees ask that the qualified patient have some “skin in the game” that could dissuade them from considering selling any quantity of legally acquired medical marijuana to a recreational buyer. At \$25, the fee is probably better described as a fee to cover the costs of processing and keeping records for the qualified patient. Perhaps at \$200, a qualified patient will be dissuaded from participating in the illegal market because they would lose their medical-usage privileges and thus, the \$200 fee is foregone without any benefit.

Figure 1 plots the number of qualified patients by state for the period 2000 through 2018. The adoption years differ by state. Moreover, note that the data are unevenly reported. Not every state provides a complete history of their number of qualified patients. So we are left with data that are quite incomplete. As a last point, the data are difficult to read because the scale is so different. There are obviously some very small states in the list, such as Delaware, New Hampshire, and Connecticut, presented alongside some very populous states. In my view, Figure 1 presents two important facts. First, there is some challenge to interpreting the data because the reporting methods vary so much across states. Ideally, one would want the number of qualified patients so that the researcher could compare apples-to-apples across states. Unfortunately, each state adopts its own set of qualifying conditions. While there is substantial overlap, the qualified-patient data are not reported in a way that permits us to take the conditions in say, Arizona, and directly apply them to what we would expect in Missouri.

Second, the raw data indicate that population matters. Large-population states will have lots of qualified patients. Arguably, a better approach is to apply the scale so that we make comparisons across states more sensibly. More specifically, we scale the number of qualified patients by population, thus relying on the fraction of population who are qualified patients to get a better sense of how the market is developing over time.

Figure 2 applies the scale approach to the state data, plotting the ratio of qualified patients to total population for nine of the eleven states represented in Figure 1. Connecticut and Michigan are omitted because each state reports only one value for the number of qualified patients. In addition, the year in which the key medical marijuana law was passed is in parentheses for each of the nine panels. Note that it often takes several years for the legislation to be implemented. In Figure 2, each panel displays a common attribute; specifically, we observe that the fraction of the population that receive qualified-patient status is increasing for the first several years after the market for medical marijuana opens. In each

Figure 1



of the nine states, there is a discernible upward trend in the fraction of population with qualified-patient identification cards. Even in Colorado and Nevada—two states with nearly 20 years of experience in the medical marijuana market—we observe, the hump-shaped pattern is consistent with the fraction of population rising for at least several years following the medical marijuana policy. The hump-shaped pattern, therefore, suggests that the maturation process continues until the ratio converges to stable, long-run value. In addition, a law change permitting recreational marijuana could also be affecting the fraction of qualified patients in both states. For Missouri, the primary takeaway is that the fraction of people with qualified-patient identification cards is increasing during the first years of the medical marijuana policy.

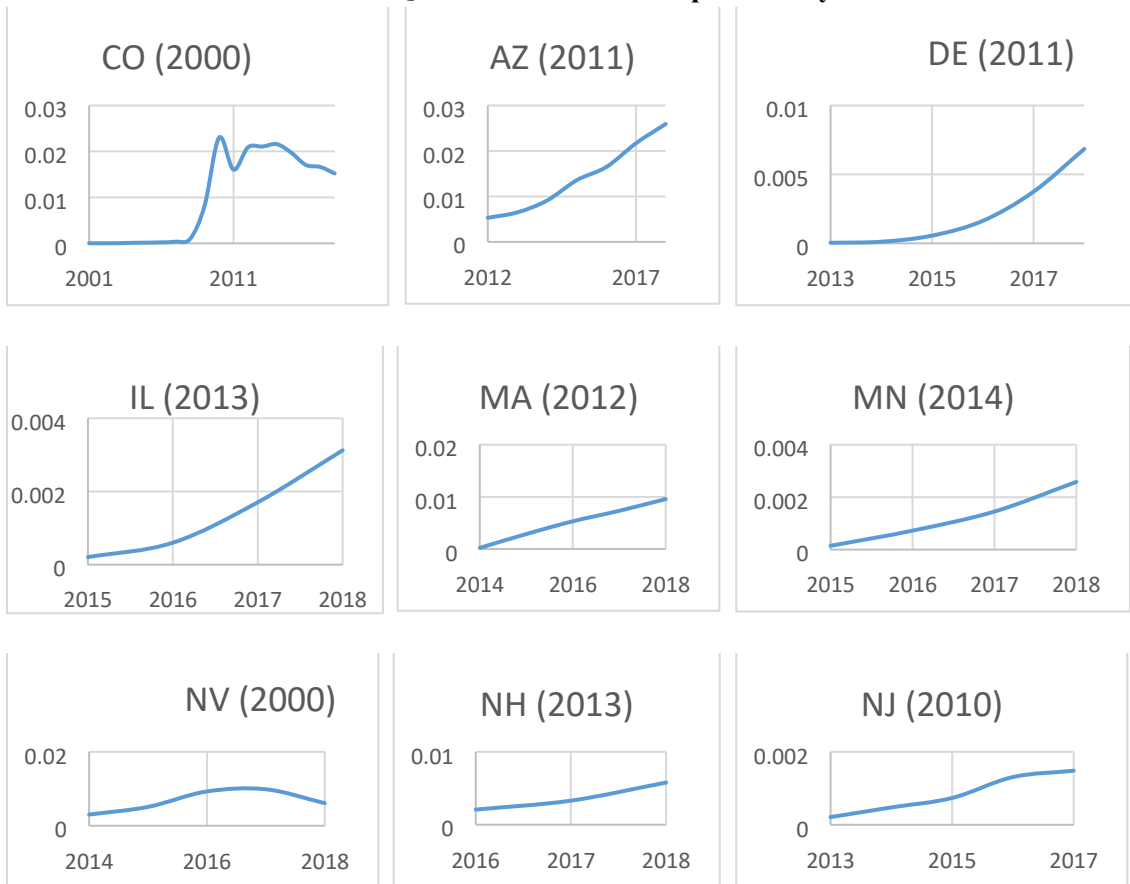
There are still some rather substantial quantitative differences across states in terms of the ratio of qualified patients to population. As Figure 2 shows, both Arizona and Delaware passed laws allowing for medical marijuana usage in 2010 and 2011, respectively. The comparison in Figure 2 shows the variability in the adoption rates in the medical marijuana market across states. By 2017, more than two percent of Arizona residents are registered as qualified to use medical marijuana while slightly more than one-half of a percent of Delaware residents are qualified. New Jersey, which passed its medical marijuana laws in 2010, is even below Delaware with less than 0.2 percent of their residents qualified to use medical marijuana in 2017.⁴

⁴ In a February 7, 2019 article, the Joplin Globe reports on Oklahoma’s progress on selling medical marijuana. According to the article, 41,716 licenses have been approved for patients and caregivers in Oklahoma. Note that Oklahoma law does not require a qualifying condition for medical marijuana. While Oklahoma may seem an

Another valuable data piece would be to know the quantity of medical marijuana sold in each state. This could be either the dollar value of final sales or the weight of final sales. Fortunately, there are several states that do report the quantity of final medical marijuana sales. By reporting these and other useful data, the reader is better able to see the challenges facing researchers trying to examine the medical marijuana market. Four states report quantities of medical marijuana sold to qualified patients: Washington, Arizona, Massachusetts, and Colorado. We will look at each state separately.

Figure 2

Ratio of Qualified Patients to Population by State



attractive comparison for Missouri because of geography, we hesitate to adopt Oklahoma’s rapid increase in qualified patients because the medical marijuana law is more liberal than Missouri’s in some key aspects. See https://www.joplinglobe.com/news/local_news/medical-marijuana-dispensaries-finding-success-inoklahoma/article_fd61351c-a0de-5548-8496-2e6023c19ccc.html for the story.

2.1 State of Washington

Washington State is a good place to start because they have conducted an analysis similar to what we are doing. In particular, we point to a 2016 report prepared for the Washington State Liquor and Cannabis Board in which 44 dispensaries responded to a survey. The question asked was: How much marijuana do you sell per month (pounds, grams, etc.)?⁵ The sample mean was 9.55 pounds per month with a standard deviation of 9.06 pounds. In other words, average annual sales per responding dispensary was 114.6 pounds. The respondents further indicated that two-thirds of the survey respondents reported sales between 5.9 pounds and 223.3 pounds per year. Thus, the evidence indicates substantial cross-dispensary variability in terms of sales by weight.

Armed with sales per dispensary, they compute the aggregate weight. With 273 dispensaries, the aggregate annual quantity is projected to be 31,285.8 pounds in Washington. In 2015, BOTEK Analysis Corp. reported there were 403 medical marijuana dispensaries while the Department of Revenue for the State of Washington reported that there were 462 dispensaries. The authors asserted that the number of dispensaries changes dramatically over time, especially since recreational marijuana was legalized in 2014. So, they apply the average pounds per month from the survey respondents, computing a simple average from the three different reports. From this approach, the authors estimated that 43,471.6 pounds of medical marijuana was sold in Washington. Note that these are not official government statistics, but are obtained from a survey. In July 2016, the State of Washington reported that 5,754 Recognition cards had been created.⁶ Based on the number of pounds and the number of Recognition cards created, the typical medical marijuana patient in Washington was consuming 7.55 pounds per year.

One needs to be a little skeptical when looking at these results. For one thing, survey responses can be untrustworthy because there is no direct way to verify the accuracy of the responses. As we will see across other states, the amount of marijuana consumption is an order of magnitude greater in the State of Washington than in other states. For Missouri's purposes, the estimated quantity per person raises significant questions about the possible flow of product from the legal medical market to the illegal recreational market.

⁵ See O'Connor, Sean, Ada Danelo, Harry Fukana, Kyle Johnson, Chad Law, and Daniel Shortt, "Estimating Canopy Size for Washington Medical Marijuana Market," a report prepared for the Washington State Liquor and Cannabis Board by the Cannabis Law & Policy Project, Seattle, WA: University of Washington School of Law, March 25, 2016.

⁶ The web address is:

<https://www.doh.wa.gov/YouandYourFamily/Marijuana/MedicalMarijuana/AuthorizationDatabase/DataandStatistics>

2.2 Commonwealth of Massachusetts

The Commonwealth of Massachusetts provides monthly reports on the number of certified patients and the quantity of medical marijuana reported. In Massachusetts, there is a distinction between the number of active patients and the number of patients who purchased medical marijuana. The fiscal year for the Commonwealth is between July 1 and June 30 (same as Missouri) so that Fiscal Year 2018 ended on June 30, 2018. In Fiscal Year 2018, the Commonwealth reports 56,216 Total Active Patient Certifications.⁷ There were 56,359 unique patients served by Registered Marijuana Dispensaries (hereafter, RMDs), selling 331,154 ounces. In other words, 20,697 pounds were sold to over 56,000 patients in 2018. The average quantity per patient was 0.367 pounds per patient. Table 3 reports the end-of-fiscal year values for total Active Patients, Total Patient Purchasing, and pounds of medical marijuana sold through RMDs. If we compute the average amount per buyer (total number of patients purchasing), the amount has steadily increased over time in the Commonwealth. In 2016, the amount per buyer was 0.32 pounds, increasing to 0.594 pounds per buyer in 2017 and 0.638 pounds per buyer in 2018.

So, we observe that the quantity per registered or qualified patient in Massachusetts is an order of magnitude lower than the quantity in Washington. If the quantities in other states are close to those in Massachusetts, we become increasingly confident that there is mismeasurement in the Washington data. Specifically, the differences are consistent with sizeable leakages between the legal and illegal markets in Washington compared with other, lower consumption-per-patient states.

Table 3

Medical Marijuana Patients and Quantities Data,

Commonwealth of Massachusetts, 2015-2018

Fiscal Year End	Total Active Patient Certifications	Total Number of Patients Purchasing	Quantity of Medical Marijuana Sold (lbs)
2015	15,535	Not reported	16.4
2016	33,170	12,752	4,077.8
2017	42,864	21,416	12,712.6
2018	56,216	32,437	20,697.1

Source: Massachusetts Medical Use of Marijuana Program: External Dashboard

⁷ See, for example, <https://www.mass.gov/files/documents/2018/07/11/2018-06-external-dashboard.pdf>. Note the difference between total active patients and number of patients served owes to certified people entering and leaving the certification process and to the fact that some certified patients do not buy.

2.3 State of Arizona

The State of Arizona produces data on the number of qualified patients and the quantity of medical marijuana sold. The data are not constructed quite the same way as data reported by the Commonwealth of Massachusetts. Arizona does track the total number of transactions at dispensaries but does not keep track of unique buyers. Table 4 reports the number of qualified patients and the number of pounds sold for Arizona for the period 2013 through 2018.⁸ The Arizona data show three similar patterns to those observed in the Commonwealth of Massachusetts. First, the amount purchased per patient in a year is nearly identical in 2018 across the two states: 0.638 pounds in Massachusetts compared with 0.655 pounds per patient in Arizona. Moreover, this quantity is about one-tenth of the amount that one would infer from the Washington data. Second, we observe that both states report an expected positive trend in the quantity of medical marijuana sold. The expected, increased quantity matches with the fact that we observed an increasing fraction of the population registered as qualified patients. As the number of people using medical marijuana increases, so does the aggregate quantity purchased. Third, we see that quantity of medical marijuana consumed per qualified Arizona patient is also increasing over time. Such evidence is consistent with

Table 4
Medical Marijuana Patients and Quantities Data,
State of Arizona, 2013-2018

Year	Number of Qualified Patients	Quantity sold at Dispensaries (lbs)	Avg Purchase Qnty per Qualified Patient (lbs)
2013	43,092	5,953.9	0.138
2014	61,272	20,150.2	0.329
2015	92,705	38,409.3	0.414
2016	114,439	58,623.5	0.512
2017	152,979	86,637.4	0.566
2018	186,002	121,915.8	0.655

Source: Arizona Annual Reports on Medical Marijuana, various issues

⁸ The data are obtained from the end-of-year (December) reports from the Arizona Department of Health Services. For an example, see <https://www.azdhs.gov/documents/licensing/medical-marijuana/reports/2018/2018-decmonthly-report.pdf>.

several alternative notions. One is that cultural stigmas associated with marijuana usage decline as residents become more accustomed to medical marijuana laws. Another is that notion that a drug's efficacy changes over time; pharmacodynamics is the study of biochemical and physiologic reactions to drug treatments. There is too little research to definitively identify the quantitative importance of these two or other potential explanations. With only two observations, it is simply worth noting that the same positive trend is present.

2.4 State of Colorado

The State of Colorado arguably produces the best statistics for researchers studying the medical marijuana market. In addition to dividing market sales by medical and recreational, Colorado's Department of Revenue reports quantity and a measure of the price of medical marijuana sold. Recall that Colorado passed laws in 2012 permitting marijuana to be sold to adults (21 and over), as recreational marijuana use became legal. The data we present here are for the period 2014 through 2017. Hence, the data will reflect the difference in markets in which only medical marijuana usage is legal and a market in which the legal restriction on recreational use is removed.

How much did the legalization of recreational marijuana affect the Colorado market? In the 2014 report by the Marijuana Policy Group, the authors concluded that recreational use was greater than projected quantities in each of the first two years after recreational use became legal. However, medical marijuana consumption remained constant.⁹ The explanation is that medical marijuana users are looking at total costs. For medical marijuana users, registration fees are considered low relative to the tax rates on recreational marijuana sales. While medical marijuana sales are subject to state and local sales taxes, recreational marijuana sales are subject to a 15 percent additional excise tax and to another special state sales tax equal to 10 percent.¹⁰ In addition, medical marijuana may be more accessible because the number of medical dispensaries is greater than the number of retail recreational outlets. For these two reasons, it is believed that the total transactions costs are lower for medical marijuana than for the recreational market. At least during the first two years, few qualified patients opted for the recreational market. If prices in the medical market and recreational markets were close, the taxes associated with recreational purchases may have induced medical marijuana patients to continue in the medical market.

⁹ See Lights, Miles K., Adam Orens, Brian Lewandowski, and Todd Pickton, "Market Size and Demand for Marijuana in Colorado," A report prepared for the Colorado Department of Revenue, 2014.

¹⁰ For example, the report states that medical marijuana sales in Denver are taxed at a 7.62 percent rate while recreational marijuana is subject to a 21.12 percent rate. The corresponding math is not provided in the report summary.

The upshot is that legalizing recreational marijuana did not eliminate all the economic frictions that existed between the medical and recreational markets.

More recently, the Marijuana Policy Group has plotted price data for recreational (adult-use) and medical marijuana between March 2014 and November 2017. In Figure 6, the data show that the market for medical marijuana is differentiated. The market for concentrates has reported price declines since 2014 with current average prices slightly above \$15 per gram. The market for flower has also seen price declines with the statewide average price just above \$5 per gram in 2014, falling to \$3.36 per gram in 2017. For edibles, the price has remained steady, holding around \$10 per 100 mg package. The evidence is consistent with product differentiation; flower is the least processed item while edibles and concentrates are produced with manufacturing costs accounting for the price difference.

The Colorado reports are very helpful in terms of adding to our understanding of changes in the market for marijuana by tracking changes in potency over time. Concentrates, especially, have become more potent over time in Colorado, meaning that there is more THC in the concentrate in 2017 compared with levels in 2014. Accordingly, the report attempts to gauge how the price per serving—a price that takes into account the amount of THC—has been changing over time. The report states that price of inhaled medical-use THC from flower has declined from \$1.79 in 2014 to \$1.11 in 2017. This price decline reflects how changes in flower price and changes in potency have both contributed to price declines in the market for medical marijuana in flower form. With the potency of concentrates increasing the most over the past three years, the price of THC per serving declined from \$3.28 in 2014 to \$1.41 in 2017.

In addition to the excellent price data in the Colorado report, several measures of quantity are also reported. In Colorado, cultivation licenses are allotted plants counts. For example, Colorado allotted 555,136 plants for medical marijuana. In 2017, the actual number of plants cultivated was 322,819. Based on the average production per plant, cultivators would harvest 341,775 pounds of flower and 68,355 pounds of trim.¹¹

To get a more complete sense of the movements in the number of plants cultivated for medical marijuana in Colorado, we present Table 5. Note that data in Table 5 are taken from December each year

¹¹ Table 7 reports potential harvest of 155 metric tons of flower and 31 metric tons of trim from the 2017 plants grown by registered cultivators. Note that a metric ton is 1000 kilograms or 2,205 pounds. In this analysis, the authors assume that the average plant will yield 70 grams (2.47 ounces) of flower and 14 grams (0.49 ounces) of trim.

Table 5
Number of Medical Marijuana Plants Cultivated

in Colorado, 2014-2017 (December)

Year	2014	2015	2016	2017
Total Number of Medical Plants Cultivated	3,590,043	3,757,022	4,116,297	3,699,348

Source: Colorado Department of Revenue

and are reported for years in which medical and recreational (adult) use are legal. In looking at December values, the number of plants cultivated for medical use fluctuated substantially between 2014 and 2016. The difference between 2014 and 2016 was 526,254 plants, or 14.7 percent of the 2014 level. By 2017, however, the total number was only about 100,000 more plants cultivated in 2014. Admittedly, one must be careful in drawing strong inference from such a small sample, but the volatility in the first four years in which recreational use was legal in Colorado does share a common element with states in which medical marijuana is legalized; namely, we observe that there is a substitution margin operating. As people substitute from the medical market to the newly legal recreational market, it appears to take several years for people to get comfortable with the newly legal market relative to the status quo. Similarly, we observe that states implementing medical marijuana laws will report consumption quantities that start low and then ramp up as people become familiar with the new legal status. The 2014-2017 period in Colorado mimics this pattern in the sense that people continued to ramp up the use of medical marijuana, measured by the number of cultivated plants, then appear to be adjusting to the legal adult market, thus substituting adult purchases for the medical use.

The Colorado Department of Revenue reports the number of licenses issued for medical marijuana. There are three categories: cultivation operations, infused product (manufacturers), and centers (dispensaries). Table 6 reports the number of each type of business and the total number of licenses under each of the three categories for the years 2014 through 2017. Interestingly, Table 6 shows that there is very little variation in the number of businesses licensed for cultivation and for dispensing medical marijuana. The fluctuations are within 4.5 percent to 5.5 percent over the four-year sample for the two categories. In contrast, the number of licenses for manufacturing infused products jumped from 163 licenses to over 250 licenses in the four-year period. In other words, the number of infused-product

Table 6

Medical Marijuana Businesses—Number of Establishment Licenses

Business Category	2014	2015	2016	2017
Centers	505	516	528	506
Cultivation Operations	748	751	788	759
Infused Product	163	202	254	254

Source: Colorado Department of Revenue

manufactures increased by 55.8 percent between 2014 and 2017. Note the infused products include edibles and concentrates, which have reported increasing market share in the Colorado medical marijuana markets over the past few years.

With data on the quantity produced and the number of licensed cultivators, it is natural to ask what the average quantity is per cultivator. We have previously reported on the quantity consumed per qualified patient, using data from Massachusetts and Arizona. Here, we report on production per cultivator. We present two measures of production per cultivator: average pounds and average number of plants. The average measures are derived from the total pounds of medical marijuana and the total number of plants. The average quantity is then obtained from the total quantities divided by the number of licenses in each year. Table 7 reports the average quantity measures per cultivator for the years 2014 through 2017. There are two things worth noting from the calculations reported in Table 7. First, the evidence suggests that the average cultivator in Colorado produces between 510 and 560 pounds of medical marijuana a year. Second, we can infer the amount of quantity per plant by dividing the pounds by the number of cultivated plants. Based on Table 7, the amount is between 0.105 pounds per plant and

Table 7

Average Quantity Measures per

Cultivation Operation in Colorado, 2014-2017

Average Quantity Measure	2014	2015	2016	2017
Pounds per cultivation operation	513.117	553.545	563.339	509.472
Plants per cultivation operation	4,800.7	5,002.7	5,223.7	4,874

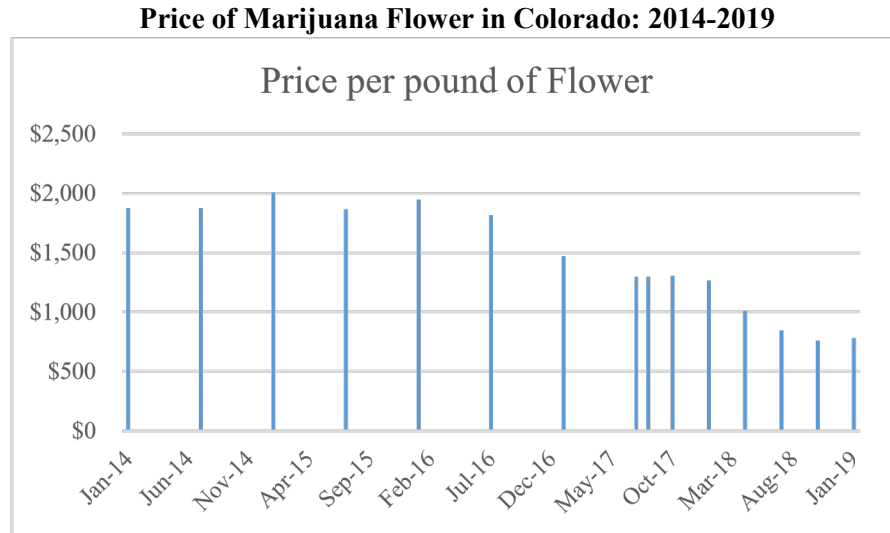
Source: authors' calculation

0.10 pounds per plant. In other words, slightly less than two ounces of medical marijuana is produced by each plant.

The Colorado Department of Revenue also reports the average market rate for recreational-use marijuana. Though the price of medical marijuana will be different, the data reported in Figure 3 is useful for the trend that emerges in retail prices since 2014. The price per pound of flower has fallen from nearly \$2,000 as recently as January 2016 to less than \$800 in late 2018 and early 2019. The price reductions are consistent with the notion that the legal changes involving marijuana trade have reduced the risk premium encoded in the old, illegal market price; that is, sellers had to be compensated with disruptions in their market that accompany being caught and therefore charge a higher price. It takes time for the new legal environment to be credible and prices to adjust accordingly. The price reduction is also consistent with productivity gains. With the new legal structure, growers are permitted to more freely experiment with production methods. Such trials yield productivity gains that result in lower prices.

Overall, the state-level data provide us with some key values to consider when constructing our measure of the amount of medical marijuana projected for Missourians and for the number of licenses needed to produce that amount. The next step is to construct a projection of the need for future marijuana consumption in Missouri combined with a projection of the necessary licenses needed to support this consumption. The trick is to make the projections on both consumption and production such that inventory buildup does not incentivize licensed participants in the supply chain to take advantage of any arbitrage opportunities that would generate record profits in the illegal recreational market. By the MMA, there is a seed-to-sale tracking system that mitigates the incentives to divert medical marijuana to the illegal recreation market. In addition, careful monitoring mechanisms discussed in the Appendix would further mitigate any such diversion pressures. On the other side of the pricing decision, the projections must not result in the price of legal, medical marijuana being prohibitively expensive in Missouri.

Figure 3



Source: Colorado Department of Revenue

3. Projections for the Missouri Medical Marijuana Market

In this section, there are two goals. First, it is necessary to quantify how much medical marijuana needs to be grown in order to serve the number of qualified patients in the state. The approach focuses on the number of qualified patients. From here, the path for the number of qualified patients and the quantity consumed both change over time. Therefore, we make projections for three years taking into account Missouri’s population. Second, it is important to examine the production and sales side of the medical marijuana market. The idea is to use the consumption side projections to project how many cultivators and how many dispensaries are needed to meet these needs.

3.1 Medical marijuana consumption

In order to get a measure of the number of qualified patients in Missouri, we use data from other states. As discussed above, it will be useful to scale the number of qualified patients relative to the total population. Also, from the evidence presented in Figure 2, there is an upward trend exhibited in the fraction of qualified patients over time in each state.

We have data for 19 states from September 2015. The number of qualified patients, total population, and the number of years since medical marijuana legislation was passed are included in Table 8. In addition, we include the number of enrolled patients as a fraction of the population and the year in

Table 8
Cross-section data on number of
Medical Marijuana Qualified Patients

	Number enrolled	Population	Number enrolled divided Population	Legislation Ratified	Yrs Open
California	75,118	39,144,818	0.001919	1996	19
Alaska	745	738,432	0.001009	1998	17
Oregon	76,723	4,028,977	0.019043	1998	17
Maine	24,377	1,329,328	0.018338	1999	16
Colorado	113,862	5,456,574	0.020867	2000	15
Hawaii	13,833	1,431,603	0.009663	2000	15
Nevada	10,019	2,890,845	0.003466	2000	15
Montana	12,672	1,032,949	0.012268	2004	11
Vermont	2,056	626,042	0.003284	2004	11
Rhode Island	12,099	1,056,298	0.011454	2006	9
New Mexico	16,700	2,085,109	0.008009	2007	8
Michigan	173,495	9,922,576	0.017485	2008	7
Arizona	80,745	6,828,065	0.011825	2010	5
New Jersey	5,236	8,958,013	0.000585	2010	5
Delaware	340	945,934	0.000359	2011	4
Connecticut	5,357	3,590,886	0.001492	2012	3
Massachusetts	13,607	6,794,422	0.002003	2012	3
Illinois	2,800	12,859,995	0.000218	2013	2
Minnesota	567	5,489,594	0.000103	2014	1

which the legislation was ratified. So the last column, “Yrs Open,” denotes the difference between the year 2015 and the year ratified.

We use present summary statistics for the fraction of population that are qualified patients. Table 9 presents the summary statistics for the full set of 20 states. The cross section shows that, on average, 0.7 percent of a state’s population are qualified patients under the medical marijuana laws. The standard deviation is 0.17 percent. The minimum fraction is 0.01 percent (Minnesota) and the maximum is 2.1 percent (Colorado).

Table 9

Summary statistics for Fraction of Population

Who Are Qualified Medical Marijuana Patients

Summary Statistic	
Mean	0.007547
Standard Error	0.001685
Median	0.003466
Mode	#N/A
Standard Deviation	0.007346
Sample Variance	5.4E-05
Kurtosis	-1.17307
Skewness	0.605192
Range	0.020764
Minimum	0.000103
Maximum	0.020867

The measure we are interested in is the fraction of Missouri’s population that will be qualified patients. In order to compute that number, we use a regression to obtain the predicted value of the fraction of population who are qualified patients. Because there is an upward trend across states, we estimate a regression with a constant term and number of years since the medical marijuana legislation was ratified.¹² The results of this regression are:

$$QP\% = 0.0025 + 0.0005 * yrs\ open \tag{1}$$

The standard error for the constant term is 0.003 and the standard error for the *yrs open* variable is 0.00027.¹³ This cross-section regression accounts for roughly 18 percent of the total variation in the fraction of population that are qualified patients across states.

¹² We would also include a variable for whether the state has legal recreational marijuana. In 2015, only Alaska, Colorado, and Maine in our data set have passed laws that allow for recreational marijuana to be used.

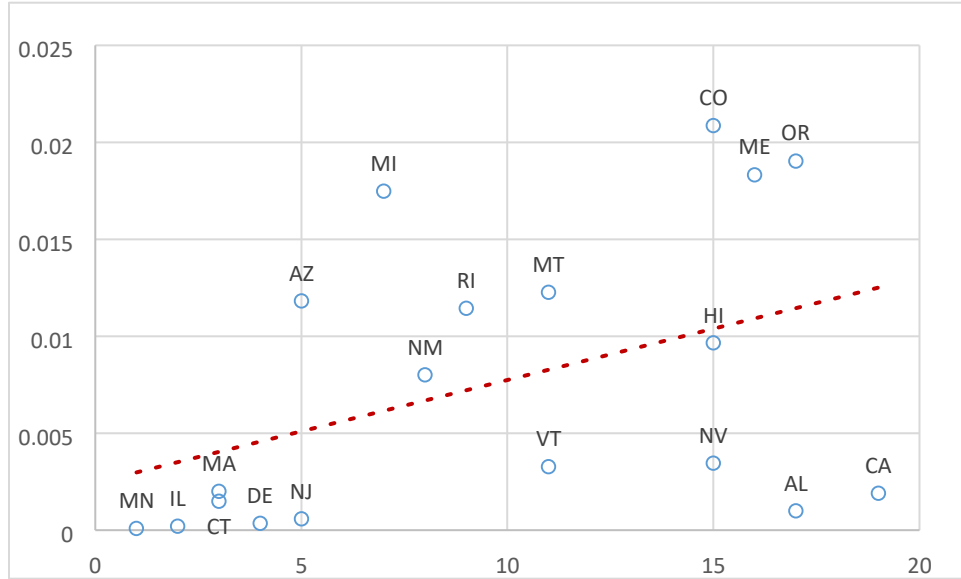
¹³ If the null hypothesis is that the coefficient on the *yrs open* variable is equal to zero, then a *t test* indicates that we would reject the null hypothesis at a 6 percent probability.

Figure 4 plots the observations for each of the nineteen states. The horizontal axis records the number of years since the medical marijuana legislation passed (relative to 2015) while the vertical axis records the fraction of the state’s population registered as qualified patients. We included a plot of the linear regression line (Equation (1)) for reference purposes. Figure 4 suggests that it becomes more

Figure 4

Scatter Plot of Fraction of Population Registered as

Qualified Patients and Years Since Medical Marijuana Laws Passed by State



difficult to accurately predict the fraction of the population that will be registered as qualified patients the more time that has passed since the medical marijuana legislation has passed. For states that passed medical marijuana between 2010 and 2015 (between zero and five on the horizontal axis), only Arizona reported a fraction of population as registered qualified patients above the regression line. Figure 4 shows that for states with more than five years since medical marijuana adoption, the prediction error—that is, the vertical distance between the point and the regression line—is, on average greater when compared with the more recent adopting states.¹⁴

¹⁴ The evidence points to the presence of heteroskedasticity. In other words, there is a relationship between the years since the medical marijuana laws being adopted and the prediction errors in the regression line. The existence of heteroskedasticity does not affect the unbiasedness of the coefficients in Equation (1), but such coefficients are inefficient. We do not presently have enough data to deal with the heteroskedasticity, so we proceed with the unbiased coefficients as a means of projecting Missouri’s fraction of the population.

We also recognize that Illinois and Connecticut do not include Chronic Pain as part of their list of qualifying conditions. It is very likely that such a qualifying condition would result in more qualified patients as a fraction of

We use the results from Equation (1) to project the fraction of Missourians that would be qualified patients. Assume that 2020 is the first year that qualified patients are enrolled. Thus, the projected fraction of Missourians who will be registered as qualified patients is represented by

$$QP\%_{MO} = 0.0025 + 0.0005 * (1) = 0.003 . \quad (2)$$

Equation (2) substitutes the value one for the variable *yrs open* in Equation (2) to project that 0.3 percent of Missourians will be registered as qualified medical marijuana patients in 2020. Similarly, we project the fraction of qualified patients for three years; that is, 2021 and 2022 where the value of *yrs open* is set equal to two for 2021 and equal to three for 2022. Table 9 reports the projected Missouri total population and the projected fraction of qualified patients in Missouri for each year. The product of the fraction and the projected population, which is the projected number of qualified patients in Missouri is also reported.

Table 9
Projected Number of Qualified Medical
Marijuana Patients in Missouri, 2020-2022

Year	Projection Fraction of Qualified Patients	Project Missouri Population	Projected Number of Qualified Patients
2020	0.002978	6,389,850	19,029
2021	0.003507	6,427,605	22,542
2022	0.004037	6,465,583	26,102

Source: authors' calculations

data show that the number of qualified patients in the first year is projected to be 19,029 people. This seems high when looking at how few people enrolled as qualified patients in Minnesota (Table 7, last row). However, in Arizona, more than 34,000 people were enrolled as qualified patients in 2012 which was the first year after the law was passed. The point is that in Arizona, the number of qualified patients in the first year was roughly equal to 0.5 percent of the state's population. Here, the projection is greater than Minnesota's fraction, but only about half of the fraction of Arizonians that were qualified medical marijuana patients.

the population for those two states. As more data are accumulated, we could assess the impacts that differences in the medical marijuana laws have on qualified patients.

The standard error of the prediction allows us to construct a confidence band around the predicted value. For regression (1), the value is 0.000467. A one standard-deviation confidence band tells us that 66 percent of the projected fraction of population who are qualified patients will be in Missouri. We report the confidence band in Table 10. Based on Table 10, we are 66 percent confident that the number of Missouri’s qualified patients will be between 16,000 and 22,000 in 2020. By 2022, the confidence band is between 23,000 qualified patients and 26,400.

Table 10

Confidence Bands for Projected Number of Missouri’s Medical Marijuana Qualified Patients

Year	Low-Fraction	High-Fraction	Low-Projection	High-Projection
2020	0.002511	0.003445	16,045	22,013
2021	0.00304	0.003974	19,540	25,543
2022	0.00357	0.004084	23,082	26,404

Source: authors’ calculations

The next step is to compute the quantity of marijuana needed to support the projected number of qualified patients. We use two different approaches to project the quantity consumed by qualified patients. One way is to use data from Arizona and Massachusetts as the basis for our calculations; specifically, each state provides data that can be used to construct the average pounds of medical marijuana purchased by qualified patients. The numbers are quite similar across these two states, and the projection requires only one calculation. The other approach is to distinguish among the different types of consumables—that is, flower, edibles, and concentrates—with the market share being the observation. In this second approach, we will need a conversion method to convert units consumed into pounds of medical marijuana.

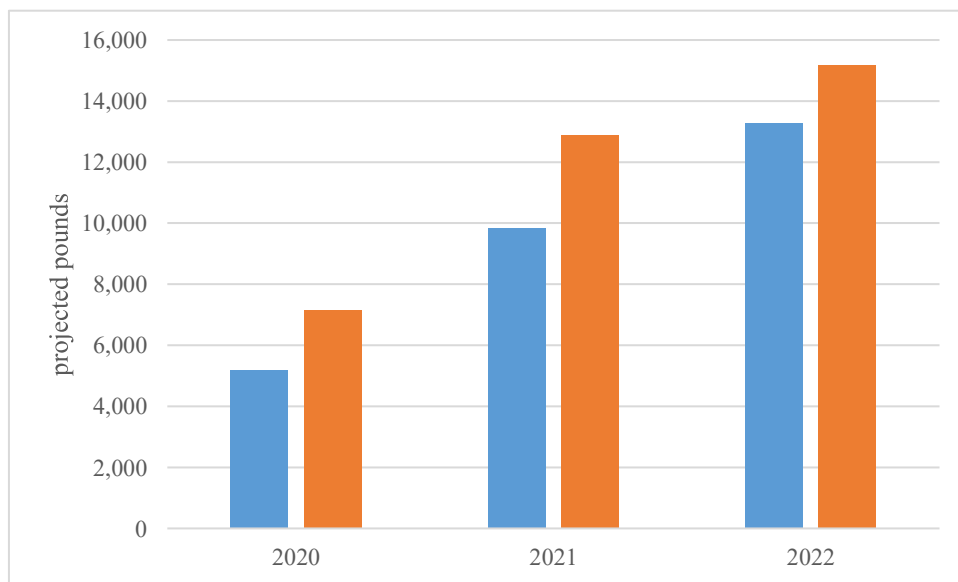
3.1.1 Average pounds consumed

The projected quantities are constructed by taking the pounds of medical marijuana per qualified patient in Arizona and Massachusetts in the first full years in which the medical marijuana program is legal. As a reminder, the quantity (in pounds) per qualified patients in Arizona was 0.329, 0.414, and 0.512 while in Massachusetts the quantity per buyer was 0.32, 0.594, and 0.638. We take the average quantity per qualified patient over the two states—which is 0.325, 0.504, and 0.575—as the projected

quantities of medical marijuana consumed per qualified patient in Missouri for 2020, 2021, and 2022, respectively.¹⁵

Figure 5 plots the projected low (blue) and high (orange) quantities for Missouri in the years 2020, 2021, and 2022. To get a confidence interval, we use the projected low number of qualified Missouri

Figure 5
Projected Quantities of Medical Marijuana
Consumed by Qualified Patients in Missouri 2020-2022



Source: authors' calculations

patients and the high number of qualified Missouri patients. The projected consumption quantity is then the product of the number of qualified patients and the average amount consumed per patient. For example, with 22,013 qualified Missouri patients in 2020—the number that is one standard deviation greater than the projected mean number of qualified patients—we project that Missourians will consume 7,143 pounds of medical marijuana. With the projected low number of qualified patients, the projected quantity is 5,207 pounds. Given the average medical marijuana quantity consumed by qualified patients, the lower and upper bounds provide a 66 percent probability that Missourians will consume between

¹⁵ There is some evidence that medical treatments lose efficacy over time. See, for example, Jones, R.T., N. L. Benowitz, and R. I. Herning, “Clinical relevance of cannabis tolerance and dependence,” *Journal of Clinical Pharmacology*, 21(1), Aug-Sept, 143S-152S.

5,207 pounds and 7,143 pounds in 2020. The range for 2021 is between 9,848 pounds and 12,874 pounds. Finally, the range for 2022 is between 13,272 pounds and 15,182 pounds. Thus, the quantity of medical marijuana consumption by qualified patients is observed to be growing over time because more patients will be qualified and because the consumption per qualified patient is increasing over time.

By the MMA, Missouri imposes a four percent tax on all medical marijuana sales. Let us assume that medical marijuana in Missouri will sell for \$350 per ounce. By our calculations, the four percent tax will raise between \$1.2 million and \$1.6 million. In 2021, the State of Missouri would raise between \$2.2 million and \$2.9 million in revenues, and in 2022, the medical marijuana tax would raise between \$2.9 million and \$3.4 million.

3.1.2 Consumption by product type

In this part of the paper, we check the results presented in Figure 1 by approaching the problem in a different way. In particular, consider the fact the medical marijuana patients consume different products. Suppose we take into account the market share for each type of medical marijuana product, using conversion methods developed in Colorado and applied by Rhode Island, it is possible to convert consumption of each type into pounds of medical marijuana.

The basic premise behind the approach is that qualified patients have different tastes in terms of treating the ailments from which they suffer. The different products, therefore, amount to choosing a THC delivery system. The technical term is pharmacokinetic dosage equivalent. In practice, edibles and concentrates are measured in units. For edibles, a 10 mg serving is the unit or dose, while concentrates are served in units. To illustrate this reporting process, Colorado reported that 172,994 pounds of marijuana flower were sold for medical consumption in 2017. During 2017, 1,851,098 units of edible marijuana were sold for medical consumption and 786,450 units of concentrate were sold for medical consumption. With units and ounces coexisting as measures of quantity sold, we run into a simple apples-to-oranges comparison.

The Marijuana Policy Group prepared a report for the Colorado Department of Revenue that developed methods to convert units of edibles and units of concentrate into the quantity of marijuana grown.¹⁶ To illustrate the conversion, the analysis finds that one ounce of flower delivers the same amount of THC as 83 units of edible products where a unit consists of ten mg of manufactured product. With respect to concentrates, one ounce of flower is equivalent to 7.72 grams of concentrate. Here, we

¹⁶ See Orens, Adam, Miles Light, Jacob Rowberry, Jeremy Matsen, and Brian Lewandowski, (2015). "Marijuana Equivalency in Portion and Dosage" A Report prepared for the Colorado Department of Revenue, April.

assume that the serving size of concentrate is one gram. Based on these conversion rates, 1,851,098 units of edibles is equivalent to consuming 22,302.4 ounces of flower, or 1,393.9 pounds of flower. With 786,450 units of concentrate, at 7.72 units equal to one ounce of flower, the aggregate equivalent amount of flower is 101,871.8 ounces of flower, or 6,367 pounds of flower. Thus, for Colorado in 2017, the amount of medical marijuana consumed is equal to the sum of flower sold, edibles-equivalent sold, and concentrate-equivalent sold. In other words, 172,994 pounds of flower plus 1,393.9 pounds of edibles-equivalents plus 6,367 pounds of concentrate-equivalents, totaling 180,754.9 pounds of medical marijuana. After the conversion, we can compute the average quantity of medical marijuana per qualified patient. Using 2017 Colorado data, the 180,754.9 pounds divided by 88,417 qualified patients yields a value of consumption equal to 2.044 pounds per qualified patients. Note that with all the enforcement measures in place, Colorado is susceptible to both external (read, non-residents) demand and smuggling across state borders.

Suppose that the market share in Missouri for the year 2020 is identical to the market share observed in Colorado in 2017. With each qualified Missourian consuming 2.044 pounds of medical marijuana, then with the projected number of qualified patients in Missouri we find a range between 32,795 pounds and 44,994.6 pounds is needed. In other words, with probability 66 percent, qualified patients in Missouri will consume between roughly 33,000 pounds and 45,000 pounds of medical marijuana in 2020. Clearly, there is a major difference in consumption patterns in Colorado compared with Arizona and Massachusetts.

By constructing the conversion equivalence, Colorado's quantity of medical marijuana consumed is smaller when compared with the amount using raw pounds of medical marijuana reported by Arizona and Massachusetts. In 2017, it is important to note that recreational marijuana was legal in Colorado. The implication is that the margin between the prices of legal medical marijuana and illegal recreational marijuana have vanished in Colorado. Hence, the smaller consumption levels for Colorado could owe to the application of the equivalency charts.

3.2 Medical Marijuana Production

The next step is to assess the number of cultivators that Missouri would need to serve the projected number of qualified patients. The best data come from Colorado. Between 2014 and 2017, we have the pounds of marijuana produced per cultivation operation. For the 2014-17 period, the average quantity is 534.8 pounds per cultivation operation.¹⁷

¹⁷ In 2019, Colorado law does not put any size, quantity, or inventory restrictions on medical marijuana cultivation operations. In the absence of size restrictions, the data we apply are derived from operations chosen by the firms to maximize profit. In contrast, Missouri laws stipulate that each indoor facility using artificial light may be limited by

For 2020, we project that Missouri’s qualified patients will need between 5,206.6 pounds and 7,143.2 pounds. Suppose Missouri cultivators are, on average, just as productive as Colorado’s medical marijuana cultivators. Then, we divide the needs by qualified patients by the average production per cultivator to get the following range for 2020: $5206.5 \div 534.8 = 9.7$ and $7143.2 \div 534.8 = 13.4$. Thus, the number of cultivators in Year 1 would be between 10 and 14. Table 11 reports the projected range of medical marijuana cultivators in Missouri for 2020, 2021, and 2022. Using the same productivity level

Table 11

Projected Number of Medical Marijuana Cultivators in Missouri, 2020-2022

	2020	2021	2022
Low	9.7	18.4	24.8
High	13.4	24	28.4

Source: authors’ calculations

per cultivator, the range of cultivators needed in 2021 is between 18 and 24. By 2022, the projected range is between 25 and 29.

According to MMA, the Department of Health and Senior Services is restricted to no less than one licensed cultivator per 100,000 people. In other words, MMA stipulates a floor; that is, the number of licenses for cultivators cannot be below one per 100,000 Missouri residents. The most recent decennial census is used to determine the floor. With the 2010 Census reporting, 5,988,927 people, the present floor is set at 60 cultivator licenses.

With 60 cultivators, there is a competitive tension that could be important for Missouri. This is especially true as we observe a tendency for growth in the number of qualified patients during the first several years of a state’s medical marijuana market. The tension is present because cultivators will be competing against one another to produce medical marijuana. Part of that competition will be in the form of producing quantity to supply both infused-product manufacturers and dispensaries. If too much quantity is produced, there will be an incentive to divert the product. The quantity pressures could be most

the Department of Health and Senior Services to 30,000 sq ft of flowering plant canopy space. Each outdoor facility utilizing natural light may be limited by the Department to 2,800 flowering plants. Each greenhouse facility using a combination of natural and artificial lighting may be limited by the Department to either 2,800 flowering plants or 30,000 sq ft of flowering plant canopy as the licensee may elect. Hence, Missouri cultivators will chose the size to maximize profits subject to the size restrictions. We do not know if the size restrictions are binding or not in Missouri. In other words, indoor cultivators may not elect to grow up to 30,000 sq ft. of flowering canopy. If they choose to grow, say, only 12,500 sq ft. then MMA’s size restriction is not binding.

intense during the early stages of the medical marijuana market as the demand for product in a new is difficult to forecast.

To illustrate the challenges of forecasting demand accurately, let us look at the data across states. If we think of medical marijuana laws as being approved in waves, there are three: states adopting between 1996 and 2007 (13 states), those adopting between 2008 and 2015 (12 states), and those adopting since 2016 (11 states).¹⁸ As we look across the states, the evidence suggests that the number of registered, or cardholding, qualified patients starts off quite low and then builds over time within a particular state (see Equation (1)).¹⁹ Based on the data we have from other states and our calibration to the Missouri population, the number of cultivators is projected to be between one-third and one-half of the 60 cultivator licenses that is the constitutional lower bound. In other words, MMA stipulates that at least 60 licenses are required. For each potential cultivator, the application decision will depend on the projected profitability. The working hypothesis is that cultivating medical marijuana is very profitable and that applications for cultivator's licenses will exceed the statutory lower bound.

One major concern is that cultivators will do what growers do: seek to produce the maximum harvest subject to limits on square footage (indoor) or number of plants (outdoor). With this objective, the risk is that the quantity produced by cultivators will exceed the quantity demanded by qualified patients when the quantities are computed at the price of recreational marijuana. Excess inventories put downward pressure on the price in the legal medical market, giving incentive to sell excess inventories in the illegal recreational market. The Department of Health and Senior Services is seeking to set up mechanisms in the market to dis-incentivize participants from diverting medical marijuana to the illegal recreational market.

There is an important friction that reduces the likelihood of excess inventories during the first year in which the MMA is implemented. In particular, there is the application process for patients and the growing cycle. More specifically, the startup frictions that operate in the medical marijuana market require the State of Missouri to identify qualified patients; and for cultivators there is the initial phase between licensing, planting, and harvesting. The 2017 report by the Colorado Department of Revenue says that the average time from seed to harvest is 132 days. It has been asserted that some indoor growers could have up to six harvests in a single year. Based on the indoor claim, the startup time could be as

¹⁸ We acknowledge that the identification of the time periods is arbitrary. The first two are chosen because they are a decade long.

¹⁹ It is not clear that the third wave of states, those adopting medical marijuana laws since 2016, will adopt the same pattern. One argument is that because states in the first and second waves—so called “early adopters”—reported the pattern of increasing numbers of qualified patients over time, more recent adopters will see a different pattern. As the country gets more comfortable, we will see that the late-adopting states will report a greater fraction of qualified patients when compared with early-adopting states.

short as 60 days. Whether 60 days or 132 days, the point is there are lags between when licensing occurs and when production is capable of being sold to qualified patients. One might argue that the lags in production are why Missouri needs to issue a number of licenses that exceed the number of growers projected to produce quantities for qualified patients. Under this strategy, the pace would slow for the number of cultivator licenses accepted while the number of qualified patients increases over time. In the short term, the risk is that a high acceptance rate for cultivator licenses results in excess production, diverting the excess product into the illegal recreational market.

For the sake of argument, we could apply a different method based on the Colorado experience to justify a liberal licensing policy for cultivators in Missouri. There are roughly 760 cultivation operation licenses in Colorado in 2017. Missouri is projected to have between 20 percent and 25 percent of the qualified patients that Colorado had in 2017. So, if we multiply the number of Colorado cultivation centers by 0.25, then Missouri would need 190 cultivation operations. Suppose medical marijuana consumption in Missouri is one-third of the consumption by medical marijuana patients in Colorado. With qualified patients in Colorado consuming nearly 2.1 pounds of marijuana per year, this would put Missouri's medical marijuana consumption at 0.7 pounds per patient per year. For our back-of-the-envelope calculation, we multiply the 190 figure by one-third, yielding a projection of 63 cultivation operations needed in Missouri. So, we can justify 60 or so cultivation centers if Missouri's medical marijuana qualified patients follow a growth trajectory similar to what we observe across other states and modest consumption patterns relative to what Colorado has reported. The back-of-the-envelope calculation, however, is based on an unusually large quantity of medical marijuana consumed per qualified patient per year. Thus, the projection is essentially unsupported by reported consumption data for the first three years of medical marijuana.

Overall, the data across states supports a vision in which medical marijuana needed to meet patient needs in the first several years will be between 20 and 30 cultivators operating with average production observed in other states. If Missouri cultivators are, on average, more productive than the average cultivator in other states, then Missouri's production would put downward pressure on the price of medical marijuana. In contrast, if Missouri cultivators are, on average, less productive than the average cultivator in other states, then the price of medical marijuana would rise. The price movements are important to the extent that they serve as an intensity gauge of the incentive to divert existing medical marijuana stocks into the illegal recreational market.

3.3 Marijuana-infused products Manufacturers

The second link in the supply chain to medical marijuana consumers is the manufacturers of infused products. What we know is the quantity of infused products sold at medical marijuana dispensaries. Armed with the conversion rates, we have some idea of the quantity of medical marijuana needed to produce the quantities sold at dispensaries. Thus, we have some notion of the inputs available for infused-product manufacturers and some measure of the output produced. Unfortunately, we do not have good data on the cost and technologies used to convert harvested plants into edibles, concentrates, and other infused products.

By MMA, there is a lower bound on the number of licenses that the state must issue for infused-product medical marijuana manufacturers. With the floor set at one license per 70,000 population, the floor number of licenses comes out to 85 licenses. Without data on costs and revenues for the infused-product manufacturers, it is challenging to project the number of operating manufacturers needed to produce the quantities.

Rather than leave the question completely unanalyzed, we look at data from Colorado. In December 2017, Colorado reports that there were 254 infused-product manufacturers serving the medical marijuana market. With four times the projected number of qualified patients in Colorado, we would expect the demand for infused-products in Missouri would be lower compared with Colorado. If we simply divide by four, we would project that Missouri would need 64 infused-product manufacturers to meet the demand for edibles and concentrates. Based on the growth of qualified patients, as soon as projections reach about 30,000 qualified patients, the Missouri market would support close to 85 infused-product manufacturers.

3.3 Dispensaries

Dispensaries are the retail outlets at which qualified patients purchase their medical marijuana. We have two sources of data on medical marijuana sales per store. Recall that University of Washington researchers surveyed dispensaries. The survey results indicated that the average amount was 114.6 pounds of medical marijuana per store per year.

In Colorado, there were 506 centers selling medical marijuana products. After converting edibles and concentrates into pounds, Colorado sold 180,754.6 pounds of medical marijuana in 2017. Divide the number of pounds per center, and the result is the average sales per center was 357.2 pounds per Colorado center in 2017.

Here, the Missouri law takes on an additional geographical component. By Amendment 2, the state cannot restrict the number of licensed dispensaries to be fewer than 24 licensed dispensaries per United States Congressional districts. Missouri presently has eight United States Congressional Districts, so that the total number of dispensary licenses permitted is 192.

First, we ask, is Missouri projected to support this number of dispensaries in the first several years? In Year 1, the projected demand for medical marijuana is between 4,700 pounds and 5,200 pounds. Using the survey data from the University of Washington report, average sales per dispensary is projected to be served by 41 to 44 dispensaries. By Year 3, Missouri is projected to have qualified patients using between 13,200 pounds and 15,100 pounds of medical marijuana. With sales equal to 114.6 pounds per dispensary, the number of dispensaries needed is projected to be between 115 and 132 dispensaries. Obviously, if using average store sales for Colorado medical marijuana centers, the number of dispensaries in Missouri would be smaller. Average store sales in Colorado were roughly three times the amount reported in the Washington report.

The simple market-oriented approach would be to issue licenses for dispensaries to satisfy the requirement set forth in Amendment 2. The idea is that there exists a shutdown condition for dispensaries that overrides the licensing restriction imposed by Amendment 2. The shutdown condition says that in a competitive industry, the price of the product must be greater than the average variable cost of the product. Thus, for high-cost dispensaries, the dictum says that even though they are licensed dispensaries, they will not operate in a competitive market for medical marijuana.

The next question is how competitive is the market for medical marijuana. Because Amendment 2 has a geographic restriction, location matters when allocating licenses to dispensaries. This is probably not a problem in more densely populated congressional districts. As Table 12 shows, the 2016 population data in Missouri shows a wide variance in the population density across congressional districts.²⁰ The most densely populated congressional district in Missouri is the 1st Congressional District which covers St. Louis City. From Table 12, we also see that this is one of the lowest income districts with only the 8th Congressional District (Southeast Missouri) reporting a lower median household income. Only five of Missouri's eight United States Congressional Districts report population densities exceeding 100 people per square mile: the 1st, 2nd, 3rd Congressional Districts (including the western suburbs of St. Louis), the 5th Congressional District (the Kansas City metropolitan statistical area), and the 7th Congressional District (the Springfield metropolitan statistical area). There are two forces at work. One is the density of

²⁰ The data for Table 12 are obtained from ARCGis. See <https://www.arcgis.com/home/webmap/viewer.html?layers=ff48bbae433442a38f6c635b8c7baf72>.

population. In cases in which the number of applications for dispensaries occur in densely populated districts, there is more intense competition among the dispensaries. The other force is the transaction cost associated with distance. In the districts reporting low population density, there is less direct competition along the price dimension. Rather, dispensaries will more likely choose locations to minimize the transaction cost for qualified patients. In other words, in the districts with 5,000 or more square miles,

Table 12

Selected Demographic Data for Missouri’s

United States Congressional Districts

District	2016 Population	Density (Pop per sq. mile)	No. of Sq miles in U.S. Congressional District	2016 Median Household Income	Projected 2021 Population
1	745,340	3,307	225.4	\$38,898	743,775
2	761,537	1,635	465.8	\$76,231	773,874
3	782,365	114	6,862.9	\$55,842	810,629
4	777,199	54	14,392.6	\$44,202	798,866
5	768,028	317	2,422.8	\$45,383	786,405
6	769,770	42	18,327.9	\$52,687	786,375
7	785,584	125	6,284.7	\$41,179	816,314
8	769,116	39	19,720.9	\$37,804	781,891

Source. U.S. Census Bureau

dispensaries will locate spatially to divide up the qualified patients as they are distributed within the district. Though less direct competition is present in the low-density population districts, the population within the district will dictate where astute dispensary owners will locate.

At the time of this report, pre-filed applications have been received by the Department of Health and Senior Services. Table 13 reports the total number of pre-filed applications by type of operation. Table 14 reports the number of pre-filed applications for dispensaries by U.S. Congressional District.

Table 13

Number of Pre-filed Applications in Missouri, by type

Type	Number of Pre-filed Applications
Cultivation Facilities	139
Medical Marijuana Infused-Product Manufacturer	71
Dispensary Facilities	252

Source: Department of Health and Senior Services, State of Missouri

According to Table 13, Missouri has received more than the MMA’s floor number of licenses for Cultivation Facilities. The number of infused-product manufacturers is nearly 84 percent of MMA’s floor number of licenses. Lastly, the total (statewide) number of dispensary facilities is already greater than the 192 dispensaries consistent with the MMA’s (statewide) floor.

However, the MMA’s floor with respect to dispensaries is by U.S. Congressional Districts. Table 14 reports the pre-filed applications for dispensary facilities by district. Note that the number of pre-filed dispensary applications exceeds the MMA’s floor in five of the eight U.S. Congressional Districts by March 31, 2019. According to Table 14, Districts 2, 6, and 8 are the only districts with pre-filed applications less than the MMA floor. Districts 6 and 8 are two of three least densely populated in Missouri. In contrast, District 2 is the second most densely populated district in the state. Given the number of pre-filed applications, the Department of Health and Senior Services does not face a binding constraint in terms of the floor on the number of licenses set by MMA. (Assuming all the pre-filed application satisfy the conditions for being valid applications that satisfy all the legal restrictions for applicants.) The question is whether it makes economic sense to grant all those licenses.

Table 14

Number of Pre-filed Dispensary Facility Applications in Missouri, by District

U.S. Congressional District	Number of Pre-filed Dispensary Applications
1	36
2	19
3	39
4	30
5	63
6	14
7	35
8	16

Source: Department of Health and Senior Services, State of Missouri

4. Economic Challenges for the Market

There are two primary challenges that Missouri’s Department of Health and Senior Services must deal with as the market for medical marijuana unfolds.

The first problem is dealing with what basically is a hidden action problem. While medical marijuana is legal to purchase by qualified patients with cards, recreational marijuana is not. The hidden action lies in the fact that from cultivators to final consumption, each stage of the process is subject to market participants choosing to sell the product—flower, edibles, concentrates, etc.—to the buyer at the highest price. The act of selling to a person not among the set of licensed providers or to qualified patients cannot be perfectly monitored or enforced. As such, the market for medical marijuana must be constructed in a way to reduce the incentives to deviate from the legal supply chain-to-qualified patient consumption path.

MMA stipulates that the Department of Health and Senior Services is required to have a seed-to-sale tracking system. A seed-to-sale tracking system has one key premise; namely, that at seed propagation or cloning, a unique identifier is assigned to the plant. At each subsequent stage—harvest and sale—the identifier is assigned to the material from that plant. In other words, say, for example, that a plant is assigned the identifier JHSE. The flower from that plant sold to a dispensary will each be identified by a new identifier that ties it to the JHSE plant. Alternatively, any materials from that plant sold to an infused-product manufacturer is assigned an identifier that links it to the JHSE plant so that all edibles and concentrates produced from that batch can be traced to a specific plant. Detailed records for each product are identified this way, especially the quantity. In this way, the regulator can follow transactions from propagating plant to final qualified-patient sale. Indeed, even if the qualified patient sells the product on the illegal recreational market, the regulator can track the product to the last legal transaction.

The purpose of the tracking process is to provide some procedure for reporting all legal transactions. In addition, in the event that illegal transactions occur, the tracking process allows regulator and law enforcement to follow the path to the last legal transaction, which could be at the propagation stage. The problem with the tracking process is that it imparts a clear punishment phase when illegal actions are undertaken. Because actual tracking events are random under limited resources, the hidden action does not vanish. In other words, there is the potential for perfect tracking from seed to final consumer, but not enough resources to actually track each transaction. Therefore, buyers and those in the supply chain of medical marijuana are trading off between the expected marginal gains from selling medical marijuana in the illegal recreational market against the expected marginal cost of being caught in such a sale.

Because the calculus is based on expected marginal gain, the price differential in the medical marijuana market and the illegal recreational market is critical. More specifically, shrinking the expected marginal gain to zero is sufficient to end legal, medical marijuana product from being sold in the illegal

recreational market. In practice, this means that the price of medical marijuana is equal to the price in the illegal recreational market.

Herein lies the trouble. What is the price of illegal recreational marijuana? The website priceofweed.com does report a price paid for a specific quantity of marijuana for a given quality. For the expected marginal gain for deviating from legal medical market to the illegal recreational market, the price is equal across the two markets. Suppose we start with the price-equalization objective. For Missouri, there are 15 posts of illegal recreational marijuana sales between February 7, 2019 and March 7, 2019. Unfortunately, the self-reporting values cannot be confirmed and therefore must be taken with some skepticism. More importantly for our ersatz regulator, there is substantial variance in the reported price for a given quantity. In the February 7-March 7 period, an ounce of high-quality marijuana could be purchased for as little as \$200 an ounce to as high as \$500 per ounce in the illegal recreational market. What price should our regulator seek in the medical marijuana market so that the equal-price condition is satisfied?

Thus, the Department of Health and Senior Services faces a Herculean task: help a market to operate so that buyers and sellers continue to act in the legal market while an illegal market operates. By the way, the product is potentially indistinguishable between the illegal and legal markets. In order to keep the legal market functioning without leakages, the price of medical marijuana must be close to the price of illegal recreational marijuana. There is an additional constitutional mandate: do not let the price of medical marijuana get “too high.” The objective is that medical marijuana remains affordable for low-income qualified patients. Simply put, the goal is to find the number of license cultivators, infused-product manufacturers, and dispensaries so that the price of medical marijuana lies in a Goldilocks zone: not too low so as to induce participants to opt for the extraordinary marginal gains from the illegal recreational market and not too high so that low-income qualified patients can afford the treatment.

5. Summary

With the Medical Marijuana Amendment, Missouri’s Department of Health and Senior Services is charged with developing rules, regulations, and especially an approach to licensing market participants in a way that minimizes the fluctuations in the price of medical marijuana treatments. Insofar as the price in a market is encoding all the competing forces operating on both producers and consumers, this is an extremely challenging objective.

In this report, our goal is to develop quantitative analysis that will assist in meeting these goals. Our results are summarized in three broad areas. First, there is the data presented by early adopters of the

medical marijuana laws. On the consumer side, the number of patients qualifying for treatment evidently goes through a maturation process. Over the first several years, we observe an increasing fraction of the state's population seeking identification as qualifying patients. We interpret this evidence across states as an increasing comfort level with the idea of medical marijuana treatment over time. With a goal to stabilize the medical marijuana market, the wise policymaker will be projecting the number of qualified patients on the age of the market. The evidence from other states also suggests that consumption per qualified patient seems to be increasing moderately over time. This could be reflecting greater comfort with the treatment or that efficacy of the treatment method diminishes with continued use. Either way, the plan forward should take the consumption intensity into account when projecting aggregate medical marijuana needs.

Second, we apply evidence from across states to project the number of qualified patients and the quantity consumed for Missouri. We report one standard deviation confidence bands for the number of qualified patients for the first three years that Missouri's medical marijuana market will be open. Thus, the probability is 66 percent that Missouri will have between 16,000 and 22,000 qualified patients in the first year (2020). By Year Three (2022), the probability is 66 percent that between 23,000 and 26,500 people will be cardholding qualified patients. There is the chance, of course, that the number of qualified patients in Missouri will lie outside these bounds.

With projections of the number of patients qualifying for medical marijuana treatment, we can generate confidence intervals for the aggregate quantity of medical marijuana needed by consumers. In 2020, we project that the aggregate quantity needed is between 5,200 and 7,200 pounds. By 2022, the projected quantities increase to between 13,300 pounds and 15,200 pounds. With a four percent tax on medical marijuana, the State of Missouri will generate additional revenues based on the price of the medical marijuana. If the price is \$350 per ounce, the State of Missouri will collect between \$1.2 million and \$1.6 million in medical marijuana taxes in 2020. (Note this figure depends also on how quickly the first sales occur.) By 2021, medical marijuana tax collections are projected to be between \$2.2 million and \$2.9 million. We project that medical marijuana tax collections will be between \$2.9 million and \$3.4 million.

Armed with the projected aggregate quantities, we use data from medical marijuana states to quantify the number of cultivators, infused-product manufacturers, and dispensaries needed to serve the set of qualified patients. With the demand for medical marijuana, it is essential that the supply chain be carefully developed. Without careful thought, the objective of price stability cannot be achieved. MMA passed in Missouri specifies the minimum number of licenses that regulators can impose. Based on the projections on the quantity needed by consumers and the average quantities produced by growers in other

states, Missouri will need only 10-15 licensed cultivators. With an amendment-minimum at around 60 cultivators, a potential problem is presented. The number of growers is likely to produce too much medical marijuana; formally, medical marijuana production will exceed quantity consumed. The bottom line is that the price of medical marijuana will begin to decline because of the excess demand, potentially inducing participants in the supply chain to divert any excess inventory to buyers in the illegal recreational market. The point is that there is an arbitrage opportunity that is always present in the market for medical marijuana because the medical product is a perfect substitute for the illegal recreational product. Hence, the product simply moves to where it is most highly valued. As such, it is clear why there is a *de facto* price floor in the market for medical marijuana.

It is more difficult to make clear projections about the number of infused-product manufacturers. Early-adopting states do not report data that would allow us to determine how many firms are needed to supply edibles, tinctures, and concentrates. With the minimum number of licenses set at around 85, it may be appropriate to issue the licenses more liberally and closely monitor the production. Though it is not legal, one could make a case the State of Missouri serve as a buyer of last resort when inventories become uncomfortably large. The intuition is that edibles and concentrates are storable in ways that plant material is not. Moreover, economics tells us that licensed producers will shut down if the price falls too low and is below average variable cost of production. In other words, even licensed manufactures may not operate if the economic conditions do not support the full 85 producers.

Lastly, the number of dispensaries licensed in Missouri has a geographic-distribution component. Dispensary licenses are allocated by United States Congressional districts. In the first few years, there may not be enough demand to keep open the minimum number of licensed dispensaries, especially in congressional districts that are sparsely populated. To date, the pre-filed applications suggest that the least densely populated U.S. Congressional Districts are below the MMA floor. This may be the underlying economics about locating in these sparsely populated districts. For the Department of Health and Senior Services, however, the MMA floor is not binding if there are insufficient number of license applications. The floor becomes binding when the number of license applications exceed the MMA stipulations. This is where the Department of Health and Senior Services is bound to issue at the minimum number of licenses for cultivators, infused-product manufacturers, and dispensaries.

Glossary

Cannabinoid—Any of the chemical compounds that the active principles of marijuana. Cannabinoids include THC, THCa, CBD, CBDa, CBN, and other naturally occurring compounds.

Concentrate—Refers to any product which refines marijuana flower into something more potent. This umbrella term includes any type of has, solventless (kief), as well as any has oils (BHO, CO2 oil, shatter, wax, etc.) and indicates that these products are a concentrated form of cannabis, carrying a higher potency.

Edible—Any marijuana product for which the intended use is oral consumption. Note that edibles do not include vape products.

Infused product—A product infused with marijuana that is intended for use of consumption other than by smoking; for example, edibles, ointments, and tinctures.

Marijuana flower—the flowering buds of the female marijuana plant that are harvested and cured for sales to processors or dispensaries.

Recreational marijuana—marijuana that is sold for purposes other than medicinal doses.

THC—Delta-9-tetrahydrocannabinol, the main psychoactive compound in marijuana

Trim—After harvest, the marijuana plant is typically trimmed of its leaf matter, leaving behind only the buds. The leftover leaves can be used for making concentrates and infused products.

Appendix I: Policy considerations

1.1 Moral, Hazard: Treatments and Monitoring

We cannot overemphasize the challenge facing the medical marijuana market in Missouri. In most cases, the market self-regulates. Because of competition, the most productive companies can sell a particular product at the lowest price, all the while remaining profitable. This is how the medical marijuana treatment could be offered to the largest class of Missouri consumers. However, we face the existence of an illegal market that uses the same product as the legal medical market. Consequently, it is the kind of technological progress and competition benefitting consumers in legal markets that creates perverse incentives in the medical marijuana market.

Because the primitive feature of the problem is hidden action by sellers, this is a kind of moral hazard problem. Typically, moral hazard is depicted as excess risk taking when people are insured against the consequences. Here, moral hazard is a broader concept, capturing the risk that sellers are willing to take because they can hide their true type. Their true type is someone willing to divert medical marijuana into the illegal recreational market.

In facing the moral hazard problem in the market for medical marijuana, the MMA and the Department of Health and Senior Services (DHSS) are already implementing some appropriate, key measures. Specifically, the license application fee serves an important role. When combined with the annual licensing fee that cultivators, infused-product manufacturers, and dispensaries must pay, moral hazard is reduced by requiring producers and sellers to face significant fixed costs before even operating in the market. In addition, the seed-to-sale tracking system plays an important monitoring role. When facing moral hazard problems, it is important to be able to identify where the product might have left the legal medical market. Seed-to-sale at least allows DHSS to monitor cultivators, infused-product manufacturers, and dispensaries and thus identify possible diverted product.

The moral hazard problem is pernicious and potentially pervasive. In order to deal with the incentive problem and limited enforcement, we recommend that the DHSS use price information to its fullest. Based on conversations we have had with DHSS regulators, they will have real-time data on transactions at four levels: (i) cultivator selling to dispensary; (ii) cultivator selling to infused-product manufacturer; (iii) infused-product manufacturer selling to dispensary; and (iv) dispensary selling to either a qualified patient or to a primary caregiver. In our view, it is critical that DHSS know the price and quantity of the medical marijuana products at each dispensary, including inventories. The price of a product encodes a tremendous amount of consumer and producer information about current and future events. In terms of

diverting product, it is the price of medical marijuana relative to the price of recreational marijuana that is so important.

It is great that DHSS has access to real-time data on price and quantity. Because illegal recreational market transactions are unobservable, there are still some big hurdles to get over for this kind of monitoring to be valuable. One source of price information in the illegal market is priceofweed.com, which self-reports price, quantity and quality of transaction by location. As problematic as self-reported data are, DHSS also has access to price data on legal recreational marijuana in states. There is a premium, most likely, on illegal recreational marijuana as sellers have to be compensated for the risk they take for undertaking illegal activities. However, price data for legal states can still provide information on the movements of prices in the illegal recreational market in Missouri. So, there are data sources that DHSS can tap to help with the monitoring.

Overall, we recommend that the reporting system include both price and quantity data at each stage of the process. Monthly reports by cultivators of harvest, inventory, and price are recorded. For infused-product manufacturers, the monthly reports need to include quantity of plant input, quantity of each type of output produced—edibles, concentrates, tinctures, for example—and price of outputs. For dispensaries, the price and quantity of each type of product sold needs to be reported monthly. If the system is setup so that inventory status and price data are recorded at dispensaries over short intervals, then price watching seems like an extremely effective way to monitor the developments in the final-consumer market. At the cultivator level, production/harvest reports must be provided in real time to the DHSS.

1.2 Vertical Integration and Competitiveness

Based on conversations with people at DHSS, there is vertical integration in the industry producing and distributing medical marijuana in other states. With cultivators, infused-produce manufacturers, and dispensaries all under the management of one parent company, there are opportunities for such vertically integrated firms to use transfer-pricing methods to drive out competing operations. With market power, a few vertically-integrated firms could result in higher consumer prices.

To illustrate the ways in which vertical integration could affect final prices, consider an industry in which the supply chain consists of three elements: a producer, an intermediate producer, and a retailer. Further, suppose there is one vertically integrated firm in this industry. The final good price is initially determined by competitive forces. However, the vertically integrated firms wants to drive out other producers. To do so, the vertically integrated producer begins to sell the product to intermediate producers at a lower price than competing producers that are not vertically integrated. Either everyone buys from the low-price vertically-integrated producer, or all other producers match the price. Either way, the set of non-

vertically-integrated producers will shut down operations because costs have not declined and profits fall below the level that renders continued operations disadvantageous.

It is natural to ask how this really helps the vertically integrated firm since they are suffering a loss as well. The vertically integrated firm is realizing larger profits at the intermediate producer level since costs have declined and selling prices remain the same. Indeed, if larger profits at the intermediate producer exactly offset the losses at the producer level, there is no harm to the vertically-integrated firm. This is the short-run view of what happens. Over a longer horizon, the producer in the vertically-integrated firm will have greater market power as all other producers cease operations, thus allowing them to eventually sell their output at a higher price and garner even larger profits for the vertically-integrated firm. In the near term, losses in one part of the supply chain can be absorbed by a vertically-integrated firm in a way that ultimately reduces competition in the industry.

The existence of vertical integration is not part of the rules set forth in MMA. It is something that regulators will want to monitor as too much market power can result in high prices in the medical marijuana market. With a goal of keeping medical marijuana treatments affordable for low-income qualified patients, DHSS needs enough competition among industry participants to meet this goal. The licensing process is setup so that there are some fixed costs that affect entry to the medical marijuana market. Those fixed costs—that is, the license application fees—are there to deal with the moral hazard problem. Therefore, DHSS is implementing a balancing act that on the one side seeks to minimize the moral-hazard problem and on the other side seeks to promote sufficient competition. The current application-fee settings seem like an appropriate fulcrum to balance these opposing forces in the medical marijuana market.

Appendix II: What if Missouri looks like Arizona

The purpose of this appendix is to consider what if Missouri's experience with medical marijuana looks more like the experience in Arizona. In particular, Figure 4 shows that Arizona reported a larger fraction of its population registered a qualified patients than would have predicted from Equation (1). In other words, the regression underpredicted what actually happened in Arizona.

To formalize our analysis in this appendix, we consider the size of the regression for the Arizona case. Five years after the medical marijuana law was implemented, Arizona reported 1.18 percent of its residents registered as qualified patients. Equation (1) predicted that five years after the medical marijuana legislation passed, 0.52 percent of the population would have registered as qualified patients. In the case of Arizona, the difference between actual and projected is 0.67 percentage points. So, we add 0.67 percentage points to the projected fraction of Missourians who will register as qualified patients under MMA. In this analysis, we report just the mean projected value qualified patients in Missouri.

We find that with the Arizona prediction error added, Missouri is projected to have 61,713 qualified patients in 2020, 65,478 qualified patients in 2021, and 69,272 patients in 2022. We assume that each qualified patient consumes 0.32 pounds a year in the first year, 0.504 pounds per year in the second year, and 0.575 pounds per year in the third year. Thus, we project that annual aggregate medical marijuana consumption would be 19,748 pounds in 2020, 33,137 pounds in 2021, and 39,831 pounds in 2022. Based on the Arizona prediction error approach, we have projected amounts of medical marijuana consumed by qualified Missouri patients.

Arizona is also an interesting anecdote with respect to cultivators. Based on conversations between DHSS and their Arizona counterparts, indoor cultivators typically have facilities that are between 10,000 and 15,000 sq. ft. Because indoor cultivators are capable of producing 0.5 pounds per sq. ft. on average annually, it is worth asking how many cultivators of this size would be needed to supply Missouri's medical marijuana needs. Assume that the cultivator has indoor capacity equal to 12,500 sq. ft. This means that each cultivator would expect to produce 6,250 pounds of marijuana for the medical market. Based on the projected pounds consumed by medical marijuana in the Arizona prediction-error scenario, Missouri would only need four 12,500-sq.-ft. cultivators in 2020. By 2021, the increase in consumption by qualified medical marijuana patients in Missouri would need only six 12,500-sq-ft cultivators. And, in 2022, consumption projections are consistent with seven 12,500-sq-ft cultivator facilities would be sufficient to supply Missouri's medical marijuana market.

Note that if Missouri's experience is closer to actual Arizona experience, tax collections would also be greater. Based on the Arizona prediction error, we project tax collected from medical marijuana would be \$4.36 million in 2020, \$7.42 million in 2021, and \$8.82 million in 2022.

If we were to use the most recent data from Arizona, we can check the math on the production per cultivation facility as early 2019. As of the last report (February 2019), Arizona has 198,157 qualified patients and caregivers. In the first two months of 2019, total amount purchased was 23,349.48 pounds of medical marijuana. If we extrapolate using the first two months of consumption data, medical marijuana consumption would be 140,096.88 pounds for 2019. Note this pace would result in each qualified patient consuming 0.71 pounds of medical marijuana in 2019, which is consistent with the notion that efficacy of medical marijuana reduces over time.

With respect to the number of cultivation facilities, there are 92 operating in Arizona.²¹ On average, each cultivation facility would be producing 1,527.8 pounds of medical marijuana. At 0.5 pounds per year, this is consistent with the average indoor cultivation facility being between 3,000 and 3,500 sq ft. Or, alternatively, a 12,500-sq-ft. cultivation facility would be producing 0.12 pounds per year.

Our goal is use these production values to estimate how many cultivation facilities would be needed to provide medical marijuana for Missourians. For the purposes of this numerical experiment, suppose that Missouri's qualified patients require 0.71 pounds of medical marijuana per patients. With 61,713 qualified patients in 2020, 65,478 qualified patients in 2021, and 69,272 patients in 2022, the quantity of medical marijuana would be 43,816.2 pounds in 2020, 46,489.4 pounds in 2021, and 48,473.1 pounds in 2022. If Missouri cultivators match the production of Arizona cultivation facilities, then divide consumption levels by 1,527.8, yielding the number of cultivators needed to supply Missouri's medical marijuana consumption equal to 29 in 2019, 31 in 2021, and 32 in 2022. The upshot is that even with our two assumptions—that Missourians will consume as much as Arizonans in Year 1 of the market and Missouri growers are only as efficient as Arizona growers—the market will not support 60 growers in the first three years.

The MMA specifies the floor for the number of licenses that DHSS is required to permit. MMA does not specify how many of those licenses are going to be associated with operating firms. Based on the data we have from other states, the calculations do not support the notion that Missouri will have 60 operating cultivation facilities supply the medical marijuana market.

²¹ The source is an email response from DHSS.