LEGALIZING MARIJUANA IN COLORADO: DISPLACEMENT OR MARKET EXPANSION?

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Abstract

This paper examines how sales at medical marijuana centers in Colorado were affected by the opening of recreational marijuana stores in 2014, where any adult can purchase without the necessity of a doctor's recommendation. We exploit differences across counties in the availability of medical and recreational marijuana to examine whether the sales growth of recreational marijuana was at the expense of sales of medical marijuana or acted by expanding the overall legal market. Our findings suggest a statistically significant but economically modest amount of displacement (less than 10 percent), demonstrating that the legalization of recreational marijuana primarily expanded the legal market.

Keywords: Marijuana Legalization, Cannibalization effect, Medical cannabis

Abbreviations:

CDPHE:	Colorado Department of Public Health and Environment
MED:	Marijuana Enforcement Division
MMC:	Medical Marijuana Center
MMJ:	Medical Marijuana
RMJ:	Recreational Marijuana
RMS:	Retail Marijuana Center

3.1. Introduction

Over the past 20 years, the United States has been at the forefront of change in marijuana policy with 37 states and the District of Columbia currently having established medical marijuana (MMJ) programs. Among these, 19 have also legalized marijuana for recreational purposes, despite its prohibition under federal law. In Colorado, where licenced medical marijuana centers (MMCs) have operated since 2009 and retail marijuana stores (RMSs) since 2014, there are currently approximately 500 of each type. The expansion of stores and greater availability of marijuana have undoubtedly contributed to the large increase in consumption. This is the first study which not only investigates whether allowing recreational marijuana (RMJ) leads to a reduction in MMJ sales, but also attempts

to quantity the displacement effect of full legalization on the medical market. The degree of substitutability between medical and recreational marijuana has implications not only for public health policy, but also for public finance, as taxation of marijuana has become a major source of tax revenue at both the state and local level.[1]

To be eligible for MMJ in Colorado, a doctor's recommendation is required. A large number of physical and mental conditions may respond to treatments with marijuana such as pain, appetite, insomnia, anxiety, and depression. Some of these are difficult to diagnose and it may therefore be possible for the patient to influence the outcome and obtain a recommendation, even in the absence of a medical reason (i.e. chronic pain, a condition declared by more than 9 out of 10 patients in Colorado, which is not medically verifiable).[2] At the MMC, the patient can choose among many different varieties (or strains) of marijuana and formulations (e.g. flowers, edibles, chemically-extracted concentrates) with different properties in terms of active ingredients. Some of the offerings will have euphoric and uplifting properties similar to illicit marijuana and the RMJ presently sold at the RMCs (Cash et al., 2020). It is conceivable that some of the sales at the MMCs have been for recreational purposes, either for the patient themselves, or for others (Wen et al. 2015).[3] Once the RMSs entered in 2014, the amount of marijuana sold by MMCs but used for recreational purposes would be expected to drop.

The staged legalization of marijuana in Colorado and the local authorities' ability to restrict marijuana within their jurisdiction allow us to examine the extent to which the medical and recreational markets are interrelated at a local level. Across Colorado, a large number of applications to operate a MMC were filed before 2012, but the processing time and general view on marijuana differed across both across counties and local governments. As seen in Figure 2, by Q3:2013 the medical market appears to have stabilized with about 500 MMCs, while in the recreational market the number of RMSs has increased steadily since their inception in Q1:2014.

[1] In Colorado, for instance, substantial tax revenues are collected both at the state, county and local level through a variety of taxes. As of January 2018, MMJ is subject to a 2.9 percent state sales tax whereas RMJ is subject to a 15 percent special sales tax in addition to a 15 percent excise tax on wholesale transfers; from the two sources the state collected 75 and 558 million USD in tax revenues so far, respectively. For 2016, they represented about 0.8 percent of the state's overall revenues (Rocky Mountain High Intensity Drug Trafficking Area, 2017). In addition, there are revenues collected from local taxes, licensees, and fees.

[2] The opening of MMC and the greater accessibility of MMJ had a dramatic effect on the number of registered patients. Just before the MMCs were allowed in 2009, there were less than 6000 patients with recommendations, which increased rapidly to approximately to 115000 in 2011, before falling to less than 90000 in 2017 (see Figure 1).

[3] Thurstone et al. (2011) show that leaking of MMJ from legal patients or dispensaries might be common. Pacula et. al (2016) found that 76 percent of those who self-identified as having a physician's recommendation reported also RMJ use. For more on classifications and uses of marijuana see Caulkins et al. (2016) and Sznitman (2017).

In this paper, we quantify the effects of the entry by RMSs on the sales at the MMCs with county-level data (Q3:2012 - Q4:2017) on the number of stores, their sales revenue, and the number of registered patients. The overall results suggest that an additional RMS in a county would decrease MMJ sales by $14200 to $57300 per quarter, which is 1.4 to 5.7 percent of the sales in the sample median county ($1.0m). In terms of sales per capita, we estimate that an additional RMS reduces medical sales per capita by between 0.1 to 0.7 percent; the elasticity at the sample means is -0.12. Finally, using the sales per MMC as the dependent variable, we find that an additional RMS is associated with a reduction in MMJ sales of $1100 to $1900 per MMC. Again, this is in the order of 0.6 to 1.1 percent of the average sales per MMC. Overall, our results suggest that the expansion of RMSs has had a statistically significant but economically small effect of the sales of MMJ.

Among the set of controls, we include the outcome of the 2012 ballot regarding legalization of RMJ, a dummy variable for whether the county is bordering another state, unemployment and the importance of the leisure industry. The sentiment towards marijuana, as proxied by the ballot, is found to be positively related to both the existence and prevalence of MMCs and RMSs, as well as sales of MMJ. Counties that border other states tend to have higher sales in the RMCs and higher sales of MMJ, in comparison to the number of MMCs or patients.

A limitation of our approach relates to the potential endogeneity occurring between sales of MMJ and the number of MMCs. Sales of a product are indeed generally driven both by the underlying demand for it and the number of shops selling it. Nevertheless, we provide several arguments to show that the opening of RMSs is most likely exogenous in view of the licensing scheme. Besides for the sentiment towards marijuana and the population of the county, we found no other factors affecting the chance to have dispensaries operating within a county.

The question of whether the marijuana sold as medicine is used recreationally is present in discussions of policy reforms elsewhere, but the paucity of reliable data limited the evaluation of already implemented reforms until recently (Pudney, 2010; Kleiman, 2015). This study is, to our knowledge, the first to quantify the effects of the entry by RMSs on the sales of MMJ, extending and complementing some of the earlier studies using survey-based methods and other indirect measures.

Pacula et. al (2016) found a large degree of overlap between medical and recreational users, and reported that registered patients use marijuana more frequently and intensively. Chu (2015) estimated the effect of the passage of MMJ laws on marijuana arrestees and admissions to treatment concluding that legal protection for patients have increased marijuana consumption. Certain policy dimensions are particularly responsible for the increased consumption, namely the existence of a legal distribution

model (Pacula et al., 2015) and the "non-specific pain" provision[4] (Wen et al., 2015) which suggest MMJ laws may have an impact on the consumption of the non-patient population. Moreover, older programs, such as in Colorado, tend to have higher enrolment rates compared to those which legalized this market recently (Williams et al., 2016). Further, Smart (2015) shows that an increase in the share of adults registered as marijuana patients increased marijuana use. Surprisingly, no evidence has been found on the increase in marijuana use among adolescents (Sarvet et al., 2018)

Through survey-based methods, Jacoby and Sovinsky (2016) investigated how full legalization would expand marijuana use by focusing on both the effect played by dispensaries in increasing accessibility, and the removal of the stigma of illegality. Despite higher price-sensitivity of young individuals, their model predicts that the largest impact would be on the population over 30 years old. Dragone et al. (2018) confirmed the intuition and found that bordering counties in Washington state experienced an increase in the consumption of marijuana after the legalization relative to the bordering counties in Oregon, a state which passed the legalization ballot just two years afterwards.

While the passage of laws allowing suppliers increases the demand for marijuana, the consequent market expansion is not captured by illicit suppliers. A growing body of empirical evidence show that the entry of legal competitors reduces the demand for illegal marijuana, and in turn the size of its black economy (Huber et al., 2016; Gavrilova et al., 2017; Brinkman and Mok-lamme, 2019; Dragone et al. 2018; Xiong, 2018). Contrary to policies which only reduce user sanctions, marijuana legalization for medical or recreational purposes has a substantial supply-side effect by allowing home cultivation, commercial production and distribution (Pacula et al., 2010). This effectively create a new legal competition for the incumbent suppliers, which in turn diminish their risk premium (Huber et al. 2016). Those involved in the illicit marijuana trade end up finding themselves in a worse economic environment characterized by increased competition and lower mark-ups which erodes the available rents (Miron and Zwiebel, 1995).

As there is no direct way to identify the rate of change in illicit cannabis market after legalization, scholars have used indirect measures by examining how the criminal behaviour of marijuana dealers had responded to the natural experiment created by new marijuana regulations. Gavrilova et al. (2017) looked at how counties close to the Mexican border where affected by MMJ laws. They found a strong reduction in systemic crime habitually committed by criminal organization which signals lower financial incentive to use violence consistent with the hypothesis that MMJ laws reduce the

[4] It refers to a situation when physicians use generic chronic pain as the eligible condition for MMJ recommendation without specifying which specific medical condition is causing the pain.

demand for illegal marijuana from Mexico[5]. Huber et al. (2016) found a connection between MMJ laws and a reduction of crime related to the illicit marijuana market at the state level[6]. The decline in supplier-related violence – along with reallocation of policing efforts and the substitution away from crime-inducing substances - is considered as a likely cause, indicating changes occurring to the entire marijuana market.

Similar effects were found after the legalization of cannabis for adults. Using census-track data from the city of Denver, Brinkman and Mok-lamme (2019) found that - in the short-term - the density of dispensaries within a neighbourhood is associated with lower crime related to marijuana trade[7]. In parallel, Dragone et al. (2018) consider the disruption of the illegal market as one of the most plausible explanation for the lowering of crime rates after the full legalization in Washington state. The policy change appears to have reduced the role for criminals in local marijuana market as the legal product has substantial competitive advantages in terms of safety and quality. In turn, the risk of being victimized while buying or consuming has declined resulting in a reduction in property crime. Rather than looking at the effect of legalization on crime by location, Xiong (2018) looks at the response of arrested marijuana trader exiting prison. He finds that their behaviour changes after legalization as they become less likely to commit future marijuana offences. They search for better opportunities, both in the legal and illegal sector since legalization have disrupted the profitability of marijuana trade.

Other studies have investigated whether MMCs are targeting recreational users. Through surveys collected outside four California' MMCs, Cooke et al. (2018) found that the characteristics of patients buying at the dispensaries differ significantly from those of individuals living in the area. Most dispensaries have clients who reflect more the population who buys MMJ in California - males with low median age - rather than the local population. This suggest that these dispensaries may be drawing in patients from other areas, and either track specific groups living there (young males) or those coming in the area for other purposes. Similarly, Hsu et al. (2018) argue that existing MMCs have responded to the competition of RMSs in different ways, depending on the socio-political support for legalization. They have emphasized their distinct identity in communities with weak support, whereas they directly compete for recreational consumers in areas with strong support for marijuana reform.

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[5] Miron & Zweibel (1995) discuss how in illicit drug markets criminal organization resort to violence to enforce contracts and to regulate disputes. Their investment in violent activity depends on the amount of disputed revenues which appears to decline after legalization. As gangs lower their demand from marijuana, they have a lower incentive to resort to violence.

[6] States with a MMJ regulation experienced a larger reduction in robberies, larcenies and burglaries compared to those states that did not.

[7] An additional dispensary was found to decrease changes in crime by 19 percent relative to the average monthly crime rate in the neighbourhood.

3.2. Institutional Background

In the United States, marijuana was listed in the Pharmacopeia until 1942. The plant was classified as a Schedule I substance by the Controlled Substance Act of 1970, meaning that it has no accepted medical use and high potential for abuse. Nonetheless, in November 2000 Colorado voters approved a ballot permitting marijuana patients and their primary caregivers to possess up to two ounces of marijuana and to grow up to six plants for medical purposes. While the ballot initiative did not address any retail supply channel, in 2007 MMCs came into place as an indirect consequence to the judiciary decision to expand the maximum patient base per caregiver beyond five patients (Kamin, 2012). An informal MMJ market was created, but very few MMCs were operating until 2009, when the Attorney General committed to not prosecuting stakeholders in compliance with state law (Anderson and Rees, 2014). This resulted in the proliferation of hundreds of new MMCs with very limited state regulations in place.[8] In parallel, the number of registered patients climbed twenty-fold between January 2009 and July 2010. The emergence of this industry became a major concern for policymakers who chose to regulate it by allowing MMCs to be active on a for-profit basis under certain operating conditions, such as distance buffers from places associated with children and problem drug users, as well as vertical integration.[9]

In November 2012, Colorado became one of the first two states to vote for marijuana legalization for all adults aged 21 or older in 2014, through a ballot measure. The legislation permits to legally possess no more than one ounce of marijuana, grow up to six plants, and transfer no more than one ounce to another adult without being remunerated. On January 1st 2014, the legislation was implemented and RMSs opened their operations, allowing any adult to legally buy marijuana and grow up to six plants for personal use.

Colorado state defers to local entities the authority to allow or prohibit the operations of MMCs or RMSs through legislative action or popular vote (Allen, 2010). As of June 2017, 26 percent of Colorado's local jurisdictions had adopted both medical and recreational marijuana operations, while 9 percent allow only one of the two segments. The remaining jurisdictions have put a total ban on marijuana sales (Hartman et al., 2017) in some cases to learn lessons from other localities. Although

[8] There was also evidence of misconduct by physicians in relation to patients' recommendations and dosage. For instance, prior to October 2012, the 12 physicians with the most recommendations had recommended MMJ for 50 percent of the patients on the registry (CDPHE, 2013).

[9] Before October 2010, there were no state licencing requirements for selling marijuana and there is no official information on the number of places that offered the product. Those who had applied for a local license by July 2010 were temporarily allowed to continue their activities as long as they also applied for a state license. The mandatory licencing scheme came in to effect on July 1st 2011.

a significant portion of Coloradans lives in communities where the sales of marijuana are not allowed, the great majority can find active dispensaries in their own counties[10].

Under the current regulations, a firm that wishes to open a MMC or RMS needs to first obtain a license from the Marijuana Enforcement Division (MED) which is the specific body tasked with regulating the marijuana industry. These licenses allow retailers to sell products to the final consumer, (other types of licenses are issued for producers and for processors) [11]. Licenses are granted for a two-year period, and local government can set license fees to cover their enforcement costs discretionally. Conditional upon having a license, local jurisdiction approval is required from the municipality where the company wants to operate (or the county if the operation is to be located in unincorporated area). Localities are thus responsible to decide how many dispensaries are allowed to open in their jurisdiction. These restrictions had an impact on the geographical distribution of new marijuana dispensaries across Denver neighbourhoods which appear to be related to poverty rate and employment (Brinkman and Mok-Lamme, 2019). On the contrary, the authors found no significant relationship between demographic factors and change in dispensary density at the county level, suggesting preference are more diluted across this geographic unit.

As noted in the introduction, both MMCs and RMSs sell an array of marijuana strains with different properties in various formulations. Their effectiveness for specific conditions has not been studied in view of a market failure in clinical trials on herbal cannabis (Fortin and Massin, 2020). There is no comprehensive information regarding price differentials at the local level for comparable items. However, the existence of a 10 percent special tax on sales at RMSs would tend to lead to higher prices, compared to a MMC. Although there are similar products at the MMC and RMS, and prices at the former likely lower, being able to purchase without a recommendation is a factor that may direct not only recreational but also some medical users to purchase at a RMS rather than a MMC. (For instance, being a registered marijuana patient may make it difficult to legally purchase firearms, Graham (2017)). For occasional users, the direct and indirect costs associated with being registered

[10] As of December 2017, about 84% and 75% of Coloradans live in counties with active MMCs and RMSs, respectively. County ordinance applies only to the unincorporated part of a county, thus incorporated city may create different laws than the county they are nested in.

[11] Under the current regulations, a MMC must grow at least 70 percent of what it sells, and it may not sell more than 30 percent of what it grows to other MCs or producers of marijuana-infused products (the "70/30 rule"). The federal prohibition indirectly set other regulations. Most dispensaries are required to operate on a cash-only basis, while it is not possible for business owners to deduct expenses from gross profits, nor get a loan from federally licensed banks (Subritzky et al., 2016). As of December 2017, no marijuana delivery service is allowed.

as a patient[12] may well outweigh the lower prices, but for frequent consumers, these costs may be small relative to the savings.[13]

3.3. Data

We examine the development of the medical market and the recreational market along several dimensions, where the segmentation is based on point-of-sale rather than purpose of use. For each county, we have information at a quarterly frequency on sales revenues (if any) and the number of outlets.[14] This data is from the MED. For each of the 64 counties in Colorado we also have information on the number of patients from the Colorado Department for Public Health and Environment (CDPHE) and several different demographic variables collected from US Census and US Bureau of Labor Statistics for the 22 quarters Q3:2012-Q4:2017. Table 1 provides descriptive statistics for the non-zero observations of each variable. Table 2 lists the key variables by county as of Q4:2017.

TABLE 1
Descriptive statistics

Variable	mean	SD	min	p25	Median	p75	max	N
REV_MED	4.95e+06	1.09e+07	20492	391718	1.0e+06	3.78e+06	5.89e+07	432
REV_RECR	7.22e+06	1.41e+07	113511	1155562	2.54e+06	6783840	1.04e+08	369
REV_TOT	1.03e+07	2.26e+07	98236	879882	3.13e+06	9026416	1.57e+08	421
#MMC	13.34	34.65	0.33	2	3	7.5	207	767
#RMS	11.72	25.8101	0.33	3	5	10.16	176	516
POP	64952.5	130320	587	4799	11636	35540	552422	1408
ln*(POP)*	9.535	1.725	6.375	8.476	9.361	10.47	13.22	1408
REV_MED/POP	24.18	19.14	2.878	11.35	19.31	30.62	106.6	432
REV_REC/POP	11.56	124.1	5.624	46.54	87.00	144.5	1178	369
REV_TOT/POP	91.87	114.4	5.855	25.11	55.76	128.6	1189	421
REV_MED/#MMC	172983	105429	13658.2	83562	167599	238150	570348	432
REV_REC/#RMS	446091	330194	46162	206237	370122	570781	2.02e+06	369
PATIENTS	1657.3	3657.3	3	76	257.5	940.5	19909	1408
PATIENTS/POP	0.025	0.013	0.004	0.016	0.022	0.034	0.084	1408

[12] Potential patients need to acquire a written diagnosis from a physician, registered with CDPHE and pay an administrative fee of $15.

[13] The amounts spent on marijuana by registered patients are substantial. At last quarter in in our sample (Q4:2017), there are 90112 registered patients in Colorado and total sales at the MMCs is approximately $97m, which means that the average purchase per registered patient is just above $1000 per quarter or about $80 per week. Even accounting for the possibility that some sales at the MMCs are diverted to out-of-state users or to friends (Belackova and Vaccaro, 2013), the sums involved are significant. There is no corresponding information on the average amount spent per customer at the RMSs, but it is likely to be substantially lower.

[14] During the first year, MED operated with a lack of resources (Room, 2014). Identification procedures gradually improved from 2012 with the licensing of MMJ businesses. However, the first monthly report which distinguishes active MMC from those with a pending application is from August 2012. In parallel, quarterly MMJ sales data are also available from the same quarter.

REV_MED/PATIENT	752.2	600.9	130.5	431.5	624.3	850.5	4568	432
PATIENTS/#MMC	341.5	426.6	18	113.7	192.5	334.5	3365	767
BALLOT	51.32	10.40	31.9	43.75	49.35	58.25	79.1	1408
LEISURE	0.101	0.14	0.004	0.037	0.056	0.092	1.004	1408
UNEMPL	4.440	2.302	1.23	2.7	3.87	5.63	16.07	1408
BORDER	0.406	0.491	0	0	0	1	1	1408

Sales revenue in the medical segment, *REV_MED*, is available from Q3:2012, when state marijuana taxes began to be collected. For counties with less than three MMCs, or where one MMC has a revenue share exceeding 80 percent, *REV_MED* is not disclosed. Sales revenue in the recreational segment, *REV_REC*, starts in Q1:2014. As with the previous variable, the value is not reported if there are fewer than three RMSs, or if one has a revenue share exceeding 80 percent[15]. We observe quarterly MMJ sales in 24 counties with 23 of them experiencing a RMS opening within their jurisdiction. MMJ sales in about 63% of the counties are observed every quarter, and in 79% of the counties are observed in at least 16 quarters. As seen in Table 1 and Table 2, sales in the two segments differ greatly across counties which is, to a large extent, due to differences in population and the number of MMCs and RMSs. The total sales in the county is denoted *REV_TOT* and is the sum of *REV_MED* and *REV_REC*.

The share of adults registered as medical marijuana patients per county ranges between 0,4% and 8,4% during the study period. We perform a preliminary analysis to examine whether the presence of a competitive legal market has affected the patient growth post-legalization. We look at the difference in the share of adults who had obtain a prescription for MMJ between the month with the minimum number of patient post-legalization (June 2017), and the month with the maximum number pre-legalization (June 2011). Appendix table 1 show that the magnitude of the drop in the registration rate differs substantially between the counties in the sample and the remaining counties, namely those with either no MMC or without a competitive MMJ market (less than three active MMCs). The reason lies on the initial registration rate of counties with a competitive MMJ market which was almost doubled compared with the remaining counties. Among the counties in the sample, those with both competitive MMJ and RMJ markets experienced a larger drop in the registration rate of about 2,7%,

[15] This reporting standard implies that the data employed here is not adequately reflecting the sales pattern in the counties with few outlets, but enables us to distinguish between true zeros and missing data. Sales at MMCs and RMSs are missing for a month in a quarter in 9 and 19 counties, respectively. We have imputed the sales for the missing months to obtain the quarterly sales, using average monthly sales in the county in the same calendar month for the adjacent years.
Appendix table 1 shows simple averages of selected characteristics for the sample and the remaining counties. Except for higher tourism, there appear to be no major differences in terms of socio-economic characteristics, preferences for legal drugs and pre-MMCs prevalence rate of marijuana patients between our sample and the group of counties which are not included in the sample.

whereas the two counties in the sample with only a competitive MMJ market experienced an average drop of 0,15%. It thus appears that the existence of a RMJ market affects the decision of users to leave the MMJ program by providing an alternative to a portion of the patient base.

The number of MMCs is denoted *#MMC* and the number of RMS is *#RMS*. Both variables refer to the average number of dispensaries that are active in the quarter. Again, the number of dispensaries displays a great deal of variation across counties, which reflects not only the population but also county and local licencing policies.

We use two variables to measure the overall demand level in a county. First, the adult population size (over 18), *POP*, should be a good proxy for the potential demand. Second, the number of registered patients, *PATIENT*, would be a reasonable predictor for demand in the medical market, as only they can buy at the MMCs.

To control for possible differences in per capita demand, we use the fraction of the population working in the leisure sector (defined as Arts, Entertainment and Recreation, as well as Accommodation and Food Services), *LEISURE*, a dummy variable for whether the county is bordering another state, *BORDER*, and the fraction of the county population that voted in favour of the ballot on Amendment in 2012, *BALLOT* (see below for details). The motivation for including *LEISURE* is that some counties are heavily reliant on tourism, and some tourists might purchase marijuana while visiting. If a county is on the state border, there may likewise be some purchases from out-of-state citizens (Hansen et al., 2017; Hao and Cowan, 2020). *BALLOT* gives an indication of the underlying sentiment of the population in the county regarding the use of marijuana.[16] Finally, we control for the level of unemployment in the county, *UNEMPL*.

We use several alternative dependent variables to capture multiple aspects of the two segments. First, we normalize sales with the county's population to get the variables *REV_MED/POP*, *REV_REC/POP*, and *REV_TOT/POP*. Variation in these variables may be driven by differences in per capita demand and are expected to be positively related to *LEISURE*, *BORDER*, and *BALLOT*. Second, we use *REV_MED/PATIENT* and *PATIENT/#MMC* to examine whether the composition of

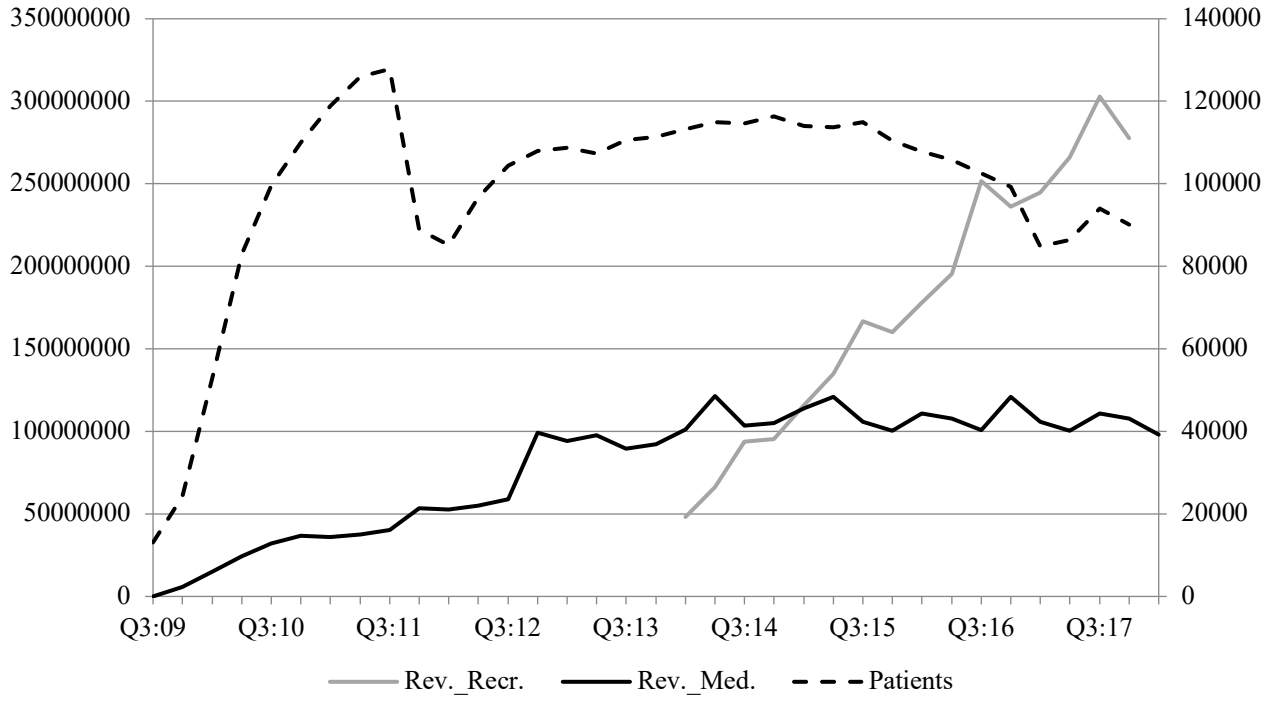
[16] In addition to the included variables, we have experimented with a number of other variables that might capture differences in per capita demand such as the fraction of university students to population, unemployment rate, average income, and the fraction of the population with a Bachelor degree. However, neither of them had any significant or consistent effect on the dependent variables we are interested in. The one exception is the election result (from the 2012 and 2016 presidential election) where the fraction voting for the Democrats candidate is highly correlated (0.85) with the variable *BALLOT*. We prefer the variable *BALLOT* since this more directly measures the sentiment regarding marijuana rather than the relative attractiveness of two different political platforms. Data collected from http://data.denverpost.com/election/results/amendment/2012/64-legalize-marijuana/ accessed Jan 27, 2017.

the patients can be explained. Finally, we examine the sales revenue per store *REV_MED/#MMC*, and *REV_REC/#RMS*.

Figures 1-4 illustrate the main variables over the period, aggregated to the state level. Figure 1 shows the sharp increase in sales of RMJ and the relatively stable sales of MMJ, and the decrease in the number of registered patients towards the end of the sample period. Figure 2 suggests that the number of MMCs reached a broadly stable level within one year from inception, but that the number of recreational stores has continued to grow since they began to open in 2014. Figure 3 illustrates the general decline in sales per medical store, and shows that RMSs have higher sales that are increasing over time. Finally, Figure 4 shows that medical sales per patient are slowly increasing and that total sales of marijuana per capita are sharply increasing.

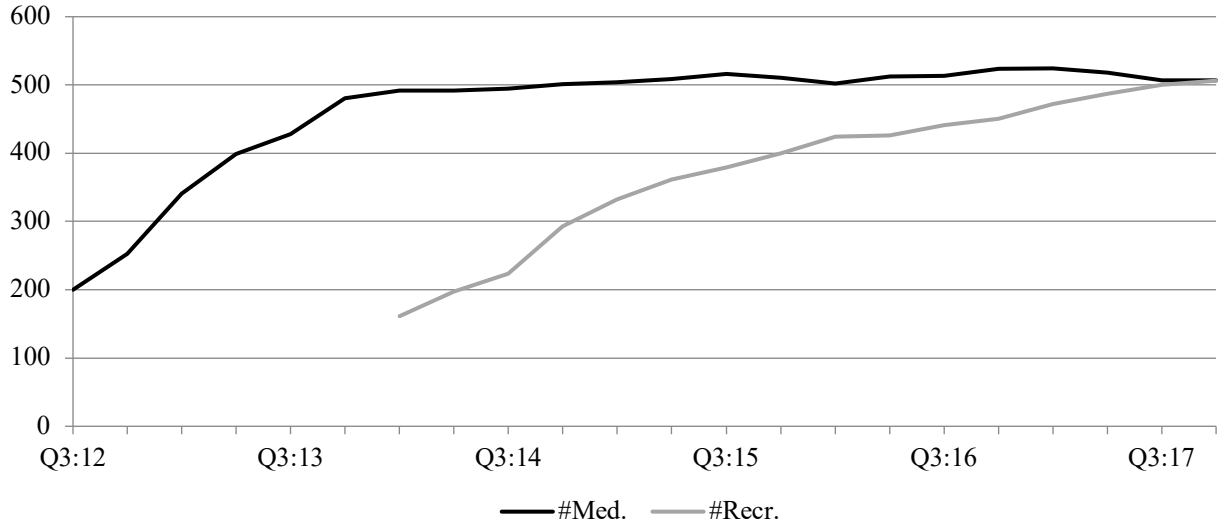
FIGURE 1

Sales and Marijuana Patients, Q3:2009 – Q4:2017



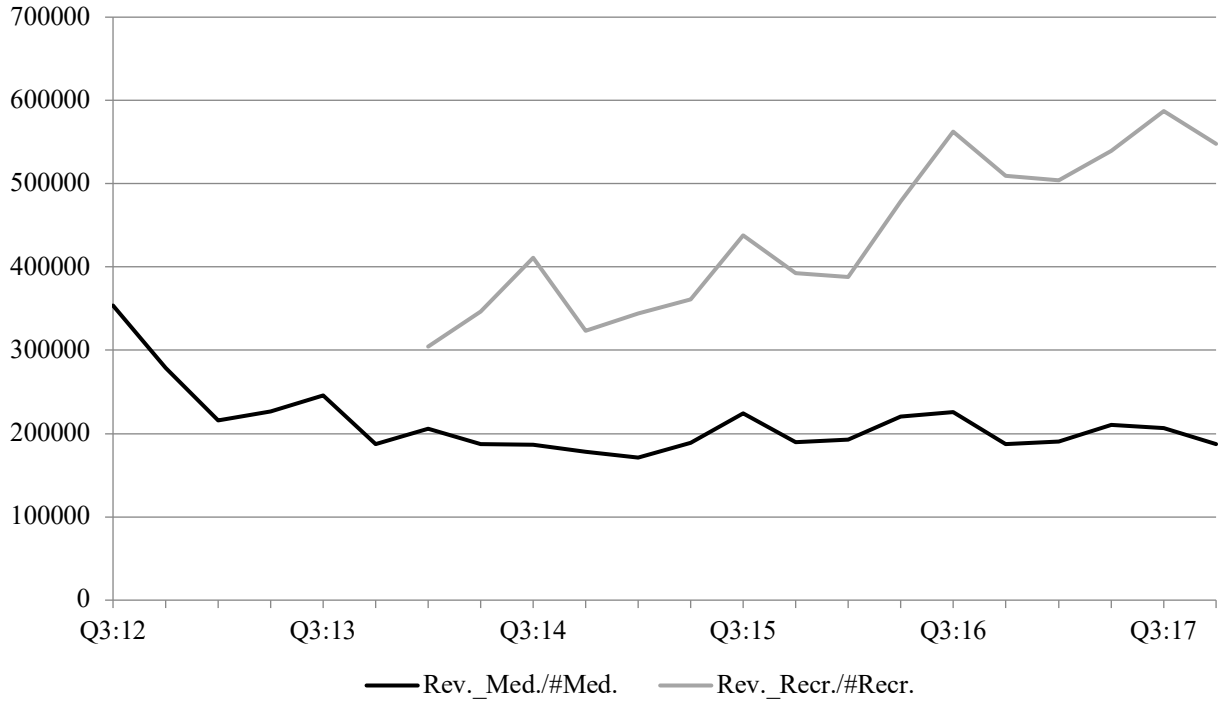
Note: State-wide sales data for the period before Q3:2012 is less reliable, as explained in the main text.
Source: MED; CDPHE.

FIGURE 2
Number of Marijuana Dispensaries, Q3:2012 – Q4:2017



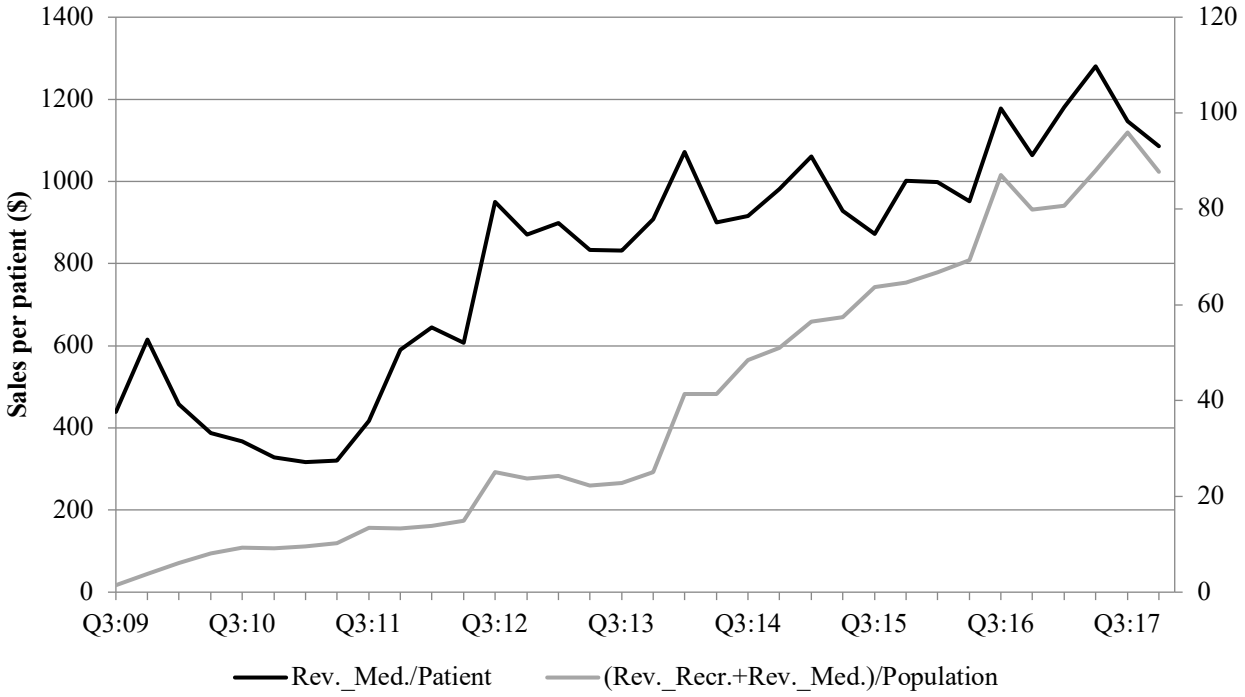
Source: MED.

FIGURE 3
Sales per Dispensary, Q3:2012 - Q4:2017



Source: MED.

FIGURE 4
Sales per Patient and Sales per Capita, Q3:2009 - Q4:2017



Note: State-wide sales data for the period before Q3:2012 is less reliable, as explained in the main text.
Source: MED; CDPHE; U.S. Census Bureau, Population Division.

3.4. Econometric model and results

Before turning to the econometric specifications, it is useful to discuss the economics of the problem. Differences across counties in sales of medical and RMJ in Colorado will be driven both by the underlying demand for the products and the number of outlets. The underlying demand will depend on county population and the per capita demand, both of which can be proxied by demographic variables. In the absence of a licencing requirement, a zero-profit condition in a free-entry model would determine the number of outlets as a (possibly concave) function of market size (see e.g. Bresnahan and Reiss 1991; Asplund and Sandin 1999; Mazzeo 2002; Seim 2006). However, given that local authorities can and do restrict the number of outlets, the accessibility of marijuana will vary across counties, and the free-entry equilibrium number of firms would be an upper bound.[17] In this paper, we do not explicitly model the details of competition within and between segments. Instead,

[17] A number of studies have used extensions of the framework of Bresnahan and Reiss (1991) in settings where there are entry restrictions (e.g. Schaumans and Verboven 2008; Ferrari and Verboven 2010; and Abraham et al 2007). Given the limited number of counties and the fact that licensing is decided at a lower (municipality or local) level make it impossible to apply these methods on our sample.

we use a parsimonious specification to examine how revenue within a segment responds to changes in the number of both types of outlets.[18]

We proceed in two steps. First, we examine the probability that a county has at least one MMC or at least one RMS at different points in time. In addition, we estimate the number of firms and the number of firms per capita. The conclusion from this is that even though market size is important, there is considerable unexplained variance, which indicates that local regulations play an important role for the number of stores. Second, we estimate the effect of MMC and RMS on the key outcome variables *PATIENT, REV_* , *REV_/POP*, *PATIENT/POP*, *REV_/#_*, *REV_MED/PATIENT*, *PATIENT/#MED*.

3.1.1. Probit and Tobit

If the free entry model is applicable, there should be a close (possibly concave) connection between market size and the number of firms. Markets that are very small will not have any firms, as the level of market demand is insufficient to cover entry costs. We test this prediction using a probit model for *#MMC*>0 in Q4:2013 (the last quarter when only MMCs were allowed) and *#MMC*>0 and *#RMS*>0 in Q4:2017 (the last quarter in our sample). The results are illustrated in Table 3.

Not surprisingly, the size of the market is a primary determinant for whether there is an MMC or RMS, and the number of these within a county. The underlying sentiment towards marijuana, as expressed by the results of the 2012 ballot, has a statistically significant effect on both the existence of at least one MMC or RMS and on the number of these outlets. In addition, the number of outlets in per capita terms is higher in the counties where the sentiment is more favourable. Of course, this could be due to more favourable treatment in the applications for licenses and/or higher underlying demand that makes it more profitable to operate. Counties that border another state tend to be more likely to have at least one MMC or one RMS, but the effect is only statistically significant in Q4: 2017 for medical centers.

[18] The exact details of the market competition (e.g. whether firms are setting prices or quantities, the amount of product differentiation within and between segments) are difficult to gauge from the information at hand. However, a simple model that would capture the essence of the revenue effects is a Cournot model where the demands in the two markets i and j with N^i and N^j firms, respectively, are interrelated $P^i = a^i - b_1^i Q^i - b_2^j Q^j$ where $Q^i = \sum_{k=1}^{N^i} q_k^i$, $b_1^i > b_2^j > 0$ and that all firms are symmetric with constant marginal costs c^i. The Nash equilibrium q^{i*} and the resulting Nash equilibrium price $P^i(q^{i*}, q^{j*})$ are decreasing in N^i and N^j. Moreover it can also be shown that the market revenue $P^i(q^{i*}, q^{j*})Q^{i*}$ is increasing in N^i and decreasing in N^j and that the revenue per firm $P^i(q^{i*}, q^{j*})Q^{i*}/N^i$ is decreasing in both in N^i and N^j.

TABLE 2

Data as of Q4:2017 listed by county in order of descending population.

County	*POP*	*#MMC*	*#RMS*	*REV_MED*	*REV_REC*	*PATIENT*	*BALLOT*
Denver	552422	200	176	4.71e+07	9.70e+07	12450	65.9
El Paso	519254	136	2	2.43e+07	N.D.	18816	49.3
Arapahoe	483960	11	28	2564502	2.80e+07	7299	52.8
Jefferson	455902	22	13	4200039	1.21e+07	9289	53.7
Adams	362131	10	27	2729659	1.71e+07	5897	56.0
Larimer	271968	14	14	3384746	1.59e+07	4876	54.6
Boulder	258999	22	35	5456849	1.99e+07	6433	66.1
Douglas	239132	0	0	0	0	2769	45.4
Weld	216615	4	4	1093926	7559947	2998	50.2
Pueblo	127116	19	33	1554058	1.06e+07	3276	54.9
Mesa	116961	1	5	N.D.	3034117	1547	46.4
Broomfield	50704	0	0	0	0	940	52.8
La Plata	44895	4	12	878514	5734578	1327	61.7
Garfield	43886	8	20	743469	5036638	740	56.8
Eagle	41728	6	8	372670	3495018	703	66.5
Fremont	39731	4	0	423317	0	1163	48.6
Montrose	32332	2	0	N.D.	0	534	42.9
Summit	25502	3	10	362241	5240838	523	69.2
Delta	24262	0	0	0	0	482	44.1
Morgan	20810	2	3	N.D.	2745415	214	42.3
Montezuma	20773	3	7.5	183616	5104946	568	48.9
Routt	20075	3	4	458474	2389708	781	62.9
Elbert	19860	0	0	0	0	252	45.7
Teller	19766	1	0	N.D.	0	850	51.5
Logan	17837	0	0	0	0	169	43.4
Chaffee	16110	1	3	N.D.	1198151	332	54.7
Pitkin	15047	3	7	171779	2546982	277	75.2
Park	14358	1	6	N.D.	1035955	427	58.1
Otero	13950	1	0	N.D.	0	295	45.7
Gunnison	13583	1	11	N.D.	1393046	125	67.3
Alamosa	12691	2	0	N.D.	0	220	56.3
Grand	12326	2	6	N.D.	1003348	274	58.4
Las Animas	11448	6	24	121598	1.22e+07	345	52.4
Archuleta	10533	1	5	N.D.	1816118	339	55.6
Moffat	9746	1	0	N.D.	0	198	47.1
Prowers	8876	0	0	0	0	139	40.7
Rio Grande	8800	0	0	0	0	158	49.1
Clear Creek	7963	5	7	103749	1513305	256	64.0
Yuma	7454	0	0	0	0	74	37.3
San Miguel	6498	1	5	20492	842543	157	79.1
Kit Carson	6354	0	0	0	0	42	37.5
Conejos	5948	0	3	0	1327431	60	45.0
Lake	5947	0	3	0	587156	147	40.2
Huerfano	5625	0	1	0	N.D.	225	43.2
Rio Blanco	4990	0	0	0	0	56	40.7
Bent	4987	0	0	0	0	71	49.4
Gilpin	4966	2	7	N.D.	565685	187	64.7
Saguache	4962	0	4	0	312354	165	64.8
Crowley	4960	0	0	0	0	90	44.3
Lincoln	4532	0	0	0	0	43	38.1
Ouray	4084	1	3	N.D.	1362628	80	61.5
Custer	3950	0	0	0	0	109	45.6
Washington	3800	0	0	0	0	45	38.5
Phillips	3263	0	0	0	0	15	37.1
Costilla	2986	0	4	0	878469	126	60.4
Baca	2824	0	0	0	0	30	36.7
Sedgwick	1925	1	1	N.D.	N.D.	49	39.5
Dolores	1625	0	0	0	0	39	45.0
Cheyenne	1360	0	0	0	0	25	35.3
Jackson	1133	0	0	0	0	17	45.7
Kiowa	1081	0	0	0	0	10	31.9
Hinsdale	629	0	0	0	0	3	48.4
Mineral	626	0	0	0	0	14	52.5
San Juan	612	0	2	0	N.D.	12	65.3

The explanatory power of the regressions (measured by the pseudo R-square) with the number of outlets is low (below 0.1) This suggests that, even after controlling for population and other observable factors, there is a great deal of variation in the accessibility of marijuana across counties. This is also evident from an examination of Table 2, which contains an overview of the key variables by county as of Q4:2017. Colorado is very diverse with counties that differ in economic, political and demographic characteristics. While there is a positive correlation between the population and the number of outlets (Denver is the largest and has the most MMCs and RMSs); among the smallest counties there are almost no outlets at all. Despite being the smallest, with a population of only 600, San Juan has two outlets. However, a number of large counties have none at all (i.e. Douglas with population of 239000) or many MMCs but few RMSs (i.e. El Paso with population of 519000 has 136 MMCs and 2 RMSs), and for many of the other counties the population size appears to be a poor predictor of the number of outlets. Overall, this suggests that differences in unobservable licencing policies play an important role for the number of outlets within a county. This also suggests that treating the number of MMCs and RMSs as exogenous in the regressions below is a reasonable approximation.

3.1.2. Panel Data Regressions

Turning next to the estimations with *PATIENTS*, *REV_*, *REV_/POP*, *REV_/#_*, *PATIENTS/POP*, *REV_MED/PATIENT*, and *PATIENT/#MED* as dependent variables with *#MMC*, *#RMS*, *#MMC/POP*, *#RMS/POP*, ln(*POP*), *BALLOT*, *LEISURE*, *BORDER*, *UNEMPL* and a linear time trend, *TIME*, as independent variables. We report random effects, fixed effects, and difference estimators in Tables 4-9. The results from the different specifications are complementary, but we wish to emphasize those from the difference specifications, which removes unobservable differences between counties and possibly different seasonal sales patterns.

For the *REV_* and *PATIENT* regressions we include ln(*POP*) in addition to *#MMC* and *#RMS* in the random effects estimator but exclude it in the fixed effects estimations, as it displays little within-county variation. The other explanatory variables are excluded as they relate to per capita sales and not to the overall market. For the regressions where we employ normalization with the population, number of outlets or the number of patients (*REV_/POP*, *REV_/#_*, *REV_MED/PATIENT*, *PATIENT/MMC*) we include *#MMC*, *#RMS*, ln(*POP*), *BALLOT*, *LEISURE*, *UNEMPL*, *BORDER*, and *TIME* in the random effects estimations but only *#MMC*, *#RMS*, *UNEMPL,* and *TIME* in the fixed effects estimations. Finally, in the difference estimations, $\Delta Y_{q,q-4}$, we include $\Delta_{q,q-4}\#MMC$ and $\Delta_{q,q-4}\#RMS$ and as an alternative include differences in the density measures $\Delta_{q,q-4}\#MMC/POP$ and $\Delta_{q,q-4}\#RMS/POP$.

TABLE 3

Medical and Recreational outlets as of Q4:2013 and Q4:2017.

	Medical segment Q4:2013			**Medical segment Q4:2017**			**Recreational segment Q4:2017**		
VARIABLE	Probit #MMC>0	Tobit #MMC	Tobit (per capita) #MMC/POP	Probit #MMC>0	Tobit #MMC	Tobit (per capita) #MMC/POP	Probit #RMS>0	Tobit #RMS	Tobit (per capita) #RMS/POP
Constant	-10.85***	-209.1***	-1.220***	-10.72***	-239***	-0.835***	-8.782***	-179.8***	-2.066***
	[2.277]	[38.75]	[0.379]	[2.435]	[46.48]	[0.234]	[1.908]	[33.52]	[0.754]
ln(POP)	0.340**	11.87***	-0.031	0.630***	16.85***	0.036**	0.239*	8.825***	-0.087
	[0.151]	[2.582]	[0.027]	[0.172]	[3.338]	[0.017]	[0.134]	[2.304]	[0.055]
BALLOT	0.150***	1.686***	0.029***	0.085***	1.219*	0.008**	0.128***	1.729***	0.055***
	[0.038]	[0.517]	[0.005]	[0.031]	[0.641]	[0.003]	[0.034]	[0.479]	[0.012]
LEISURE	0.672	-10.05	0.126	4.053	15.63	0.350	-0.026	-21.14	-0.248
	[3.139]	[33.07]	[0.355]	[3.635]	[45.10]	[0.245]	[2.385]	[33.92]	[0.825]
BORDER	0.777	-0.896	0.061	0.858*	0.243	0.064	0.690	1.758	0.166
	[0.500]	[9.125]	[0.096]	[0.517]	[10.75]	[0.058]	[0.457]	[8.216]	[0.198]
Sigma		28.17***	0.310***		32.69***	0.186***		25.70***	0.644***
		[3.282]	[0.039]		[3.839]	[0.024]		[3.067]	[0.082]
Marg. Effect POP	0.121			0.189			0.090		
Marg.Effect BALLOT	0.053			0.036			0.048		
Observations	64	64	64	64	64	64	64	64	64
Pseudo-R^2	0.550	0.098	0.465	0.514	0.098	0.718	0.449	0.093	0.235
Log-likelihood	-19.74	-179.3	-21.84	-21.41	-179.6	-4.710	-24.31	-173.2	-48.65

Notes: Standard errors are in brackets below estimated coefficients. All estimates for marginal effects were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

TABLE 4

Number of Patients and Medical Marijuana Sales, 3Q:2012- 4Q:2017

	Patients			**Medical Sales**		
VARIABLE	RE Patients	FE Patients	Diff Patients	RE *REV_MED*	FE *REV_MED*	Diff Δ*REV_MED*
Constant	-2.03e+04***	6458***	-650.2***	-5.53e+06***	1.65e+06**	1.01e+06*
	[2476]	[404.8]	[81.65]	[1.58e+06]	[7.58e+05]	[5.29e+05]
#MMC[1]	47.69***	43.561***	28.59***	2.20e+05***	1.57e+05***	1.69e+05***
	[3.840]	[3.976]	[3.879]	[5572]	[7447]	[8056]
#RMS[1]	-41.02***	-39.539***	3.350	-1.42e+04**	-2.13e+04***	-5.73e+04***
	[2.811]	[2.798]	[3.159]	[6095]	[5240]	[6109]
ln*(POP)*	2415.2***			5.52e+05***		
	[227.2]			[1.34e+05]		
TIME	-102.1***	-93.23***		-3.15e+04	12.061	-2.70e+04
	[14.43]	[14.31]		[29566]	[26803]	[21218]
UNEMPL	-291.1***	-295.3***	-380.7***	-1.27e+04	-2.22e+04	-1.22e+05*
	[50.682]	[50.559]	[62.15]	[1.02e+05]	[94703]	[71292]
$\mathcal{E}_{\#MMC}$	0.230	0.214		0.996	0.710	
$\mathcal{E}_{\#RMS}$	-0.106	-0.104		-0.034	-0.051	
Observations	432	432	352	432	432	352
Groups	24	24	23	24	24	23
R^2 *within*	0.443	0.447	0.350	0.590	0.600	0.528
R^2 *between*	0.870	0.584	0.012	0.972	0.969	0.835
R^2 *overall*	0.868	0.569	0.181	0.951	0.946	0.579

Notes: Standard errors are in brackets below estimated coefficients. Constant in fixed effects estimator is average of individual fixed effects. All estimates for elasticity were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

[1]In the difference specification the variable is defined as the year-on-year change, Δ#_.

TABLE 5

Recreational and Total Marijuana Sales, 3Q:2012- 4Q:2017

	Recreational Sales			**Total Sales**		
VARIABLE	RE *REV_REC*	FE *REV_REC*	Diff *ΔREV_REC*	RE *REV_TOT*	FE *REV_TOT*	Diff *ΔREV_TOT*
Constant	-1.63e+07***	-7.44e+06***	2.16e+06*	-1.81e+07***	-3.90e+06*	3.72e+06***
	[2.91e+06]	[2.40e+06]	[1.31e+06]	[2.64e+06]	[2.12e+06]	[1.26e+06]
#MMC[1]	-2.49e+05***	-6.47e+04	-1.55e+05***	1.95e+05***	54257**	49487***
	[24467]	[78415]	[36464]	[13005]	[27512]	[15180]
#RMS[1]	7.51e+05***	8.07e+05***	2.80e+05***	4.63e+05***	4.93e+05***	1.93e+05***
	[31085]	[32673]	[15511]	[15806]	[17332]	[11679]
ln*(POP)*	1.35e+06***			1.52e+06***		
	[2.29e+05]			[2.10e+05]		
TIME	86.576	1.16e+05*	1.818.518	1.36e+05**	2.75e+05***	-4.16e+04
	[58963]	[67196]	[44869]	[59972]	[74977]	[44567]
UNEMPL	43.207	3.90e+05	-2.33e+05	1.56e+05	7.45e+05***	-3.87e+05**
	[2.45e+05]	[2.96e+05]	[1.98e+05]	[2.04e+05]	[2.69e+05]	[1.70e+05]
$\mathcal{E}_{\#MMC}$	-0.552	-0.137		0.351	0.098	
$\mathcal{E}_{\#RMS}$	1.598	1.738		0.580	0.617	
Observations	369	369	318	469	469	351
Groups	31	31	28	27	27	25
R^2 *within*	0.748	0.755	0.585	0.829	0.840	0.447
R^2 *between*	0.971	0.950	0.933	0.989	0.958	0.919
R^2 *overall*	0.942	0.911	0.707	0.960	0.922	0.633

Notes: Standard errors are in brackets below estimated coefficients. Constant in fixed effects estimator is average of individual fixed effects. All estimates for elasticity were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

[1]In the difference specification the variable is defined as the year-on-year change, Δ#_.

TABLE 6

Patients and Medical Sales per capita, 3Q:2012 - 4Q:2017

VARIABLE	**Patients per capita**				**Medical Sales per capita**			
	RE PAT/POP	FE PAT/POP	Diff PAT/POP	Diff PAT/POP	RE *MED/POP*	FE *MED/POP*	Diff *MED/POP*	Diff *MED/POP*
Constant	0.115***	0.053***	-0.005***	-0.005***	-83.65**	32.82***	-1.145	-1.939*
	[0.021]	[0.002]	[0.000]	[0.001]	[42.56]	[3.760]	[0.948]	[1.032]
#MMC[1]	0.016***	0.013***	-0.000		49.52***	47.46***	27.47***	
	[0.003]	[0.003]	[0.002]		[5.052]	[5.214]	[3.510]	
#RMS[1]	-0.009***	-0.010***	0.002		-16.03***	-16.88***	-7.840***	
	[0.001]	[0.001]	[0.001]		[2.201]	[2.266]	[2.892]	
#MMC/POP[1]				0.000***				0.387***
				[0.000]				[0.042]
#RMS/POP[1]				0.000				-0.150***
				[0.000]				[0.035]
ln*(POP)*	-0.005***				6.587***			
	[0.001]				[2.247]			
TIME	-0.001***	-0.001***			-0.555***	-0.589***		
	[0.000]	[0.000]			[0.137]	[0.123]		
UNEMPL	-0.002***	-0.002***	-0.002***	-0.002***	-1.713***	-1.944***	0.257	0.863
	[0.000]	[0.000]	[0.000]	[0.000]	[0.460]	[0.428]	[0.698]	[0.669]
BALLOT	-0.000				0.638			
	[0.000]				[0.410]			
LEISURE	0.000				3.768			
	[0.003]				[5.793]			
BORDER	-0.002				6.196			
	[0.003]				[6.549]			
$\varepsilon_{\#MMC}$	0.106	0.086			0.437	0.410		
$\varepsilon_{\#RMS}$	-0.05	-0.054			-0.12	-0.123		
Observations	432	432	352	352	432	432	352	352
Groups	24	24	23	23	24	24	23	23
R^2 *within*	0.602	0.603	0.200	0.202	0.398	0.395	0.154	0.210
R^2 *between*	0.559	0.147	0.000	0.117	0.340	0.136	0.559	0.379
R^2 *overall*	0.622	0.289	0.145	0.191	0.391	0.231	0.225	0.234

Notes: Standard errors are in brackets below estimated coefficients. Constant in fixed effects estimator is average of individual fixed effects. All estimates for elasticity were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

[1]In the difference specification the variable is defined as the year-on-year change, $\Delta\#\_$.

TABLE 7

Recreational and Total Sales per capita, 3Q:2012 - 4Q:2017

VARIABLE	**Recreational Sales per capita**				**Total Sales per capita**			
	RE *REC/POP*	FE *REC/POP*	Diff *REC/POP*	Diff *REC/POP*	RE *TOT/POP*	FE *TOT/POP*	Diff *TOT/POP*	Diff *TOT/POP*
Constant	-124.1	-7.784	35.58***	33.83***	71.16	25.83	13.97***	11.58**
	[145.7]	[33.39]	[8.962]	[12.34]	[164.5]	[19.25]	[3.542]	[4.627]
#MMC[1]	169.9***	187.6***	14.94		109.4***	89.881***	20.96*	
	[27.98]	[28.84]	[20.21]		[18.94]	[18.613]	[12.08]	
#RMS[1]	338.4***	364.4***	139.4***		134.8***	115.134***	112.6***	
	[19.98]	[21.24]	[13.59]		[11.26]	[11.377]	[8.802]	
#MMC/POP[1]				-1.360*				-0.186
				[0.716]				[0.182]
#RMS/POP[1]				0.856***				0.425***
				[0.315]				[0.149]
ln*(POP)*	30.85***				-0.386			
	[9.035]				[9.830]			
TIME	0.340	0.633			3.609***	3.017***		
	[1.218]	[1.090]			[0.742]	[0.666]		
UNEMPL	-22.46***	-21.26***	1.840	-11.84***	-1.058	-3.892	-1.663	-10.92***
	[5.234]	[5.055]	[3.993]	[4.313]	[2.591]	[2.389]	[2.469]	[2.897]
BALLOT	-3.262**				-1.536			
	[1.542]				[1.730]			
LEISURE	-22.32				40.91*			
	[33.05]				[23.443]			
BORDER	38.46				86.66***			
	[27.69]				[32.791]			
$\mathcal{E}_{\#MMC}$	0.273	0.305			0.197	0.180		
$\mathcal{E}_{\#RMS}$	1.179	1.281			0.333	0.317		
Observations	369	369	318	318	469	469	351	351
Groups	31	31	28	28	27	27	25	25
R^2 *within*	0.611	0.613	0.267	0.063	0.601	0.600	0.363	0.083
R^2 *between*	0.560	0.522	0.539	0.015	0.692	0.705	0.294	0.006
R^2 *overall*	0.544	0.492	0.382	0.029	0.481	0.540	0.333	0.058

Notes: Standard errors are in brackets below estimated coefficients. Constant in fixed effects estimator is average of individual fixed effects. All estimates for elasticity were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

[1] In the difference specification the variable is defined as the year-on-year change, Δ#_ and Δ#_*/POP*, respectively.

TABLE 8

Medical and Recreational Sales per dispensary, 3Q:2012 - 4Q:2017

	MMJ Sales per Medical center			**RMJ Sales per recreational stores**		
VARIABLE	RE REV_MED/ #MMC	FE REV_MED/ #MMC	Diff ΔREV_MED/ #MMC	RE REV_REC/ #RMS	FE REV_REC/ #RMS	Diff ΔREV_REC/ #RMS
Constant	-8.74e+05***	2.19e+05***	668.0	-1.27e+06***	3.42e+05***	1.08e+05***
	[1.51e+05]	[28774]	[6614]	[3.88e+05]	[1.19e+05]	[24266]
#MMC[1]	-1079***	-1432***	-1849***	2926*	2.478	-3.622
	[223.5]	[282.6]	[340.3]	[1519]	[3873.498]	[2769]
#RMS[1]	220.3	284.903	540.4**	-6615***	-5639***	-1.72e+04***
	[191.3]	[198.9]	[265.3]	[1565]	[1613]	[2342]
ln(POP)	79128***			1.62e+05***		
	[8038]			[23681]		
TIME	-2539**	-2432**		22562***	17755***	
	[1077]	[1017]		[3523]	[3319]	
UNEMPL	3.172	2.197	16898***	-2.66e+04*	-3.85e+04***	-3.96e+04**
	[3676]	[3593]	[5690]	[14189]	[14640]	[15937]
BALLOT	3064**			-5.200		
	[1382]			[3886]		
LEISURE	30.199			3.14e+05***		
	[41275]			[90099]		
BORDER	43305**			1.65e+05**		
	[21694]			[68975]		
$\varepsilon_{\#MMC}$	-0.141	-0.185		0.102	0.085	
$\varepsilon_{\#RMS}$	0.015	0.020		-0.234	-0.197	
Observations	432	432	336	369	369	251
Groups	24	24	22	31	31	28
R^2 *within*	0.199	0.200	0.155	0.320	0.292	0.222
R^2 *between*	0.791	0.154	0.001	0.655	0.002	0.033
R^2 *overall*	0.600	0.035	0.116	0.612	0.032	0.067

Notes: Standard errors are in brackets below estimated coefficients. Constant in fixed effects estimator is average of individual fixed effects. All estimates for elasticity were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

[1]In the difference specification the variable is defined as the year-on-year change, Δ#_.

TABLE 9

Medical Sales per Patient and Patients per Medical Center, 3Q:2012 - 4Q:2017

	MMJ sales per patient			**Patients per medical center**		
VARIABLE	RE REV_MED/ PATIENT	FE REV_MED/ PATIENT	Diff ΔREV_MED/ PATIENT	RE PATIENT/ #MMC	FE PATIENT/ #MMC	Diff ΔPATIENT/ #MMC
Constant	-1.022	594.2***	61.32**	-717.0	340.134***	-20.988
	[670.5]	[112.7]	[29.50]	[569.7]	[79.757]	[17.724]
#MMC[1]	7.808***	6.484***	5.759***	-2.896***	-2.165**	-4.155***
	[0.918]	[1.107]	[1.207]	[0.953]	[1.045]	[1.110]
#RMS[1]	4.847***	5.078***	-6.168***	0.598	0.375	1.557*
	[0.754]	[0.779]	[1.003]	[0.720]	[0.730]	[0.884]
ln(POP)	46.917			141.9***		
	[35.71]			[35.31]		
TIME	-1.159	-4.476		-6.513**	-4.839	
	[4.287]	[3.984]		[3.291]	[2.965]	
UNEMPL	13.524	0.644	58.77***	19.03*	22.251**	25.170**
	[14.613]	[14.07]	[19.01]	[9.904]	[9.283]	[11.611]
BALLOT	14.23**			-7.136		
	[6.225]			[6.202]		
LEISURE	258.9			-117.1		
	[169.3]			[160.9]		
BORDER	180.9*			60.89		
	[98.08]			[113.6]		
$\varepsilon_{\#MMC}$	0.24	0.193		-0.122	-0.09	
$\varepsilon_{\#RMS}$	0.80	0.081		0.014	0.009	
Observations	432	432	352	671	671	524
Groups	24	24	23	36	36	35
R^2 *within*	0.325	0.319	0.214	0.137	0.139	0.046
R^2 *between*	0.859	0.836	0.063	0.445	0.009	0.015
R^2 *overall*	0.792	0.769	0.077	0.384	0.043	0.032

Notes: Standard errors are in brackets below estimated coefficients. Constant in fixed effects estimator is average of individual fixed effects. All estimates for elasticity were calculated using the mean values for the independent variables. *, **, and ***indicate significance at the 90%, 95%, and 99% levels, respectively.

[1] In the difference specification the variable is defined as the year-on-year change, Δ#_.

Regressions with patients (*PATIENTS*) and revenue (*REV_*). Before proceeding on the effect of the number of outlets on the number of patients, note that being registered as a patient can be influenced by the person in question, and thus there is an inherent endogeneity/causality problem in interpreting the coefficients: an increase in accessibility of MMC might result in people to registering as patients or, alternatively, that more patients increase the number of MMCs. Bearing this in mind, the positive coefficient on *#MMC* in table 4 demonstrates an association between the number of MMCs and the number of patients. Each quarter on average, there are between 28 and 47 additional patients per additional MMC operating. On the contrary, RMS has a negative association with the number of patients. Each RMS is associated with an average reduction of about 40 patients. Among the controls, the negative and significant time trend shows that the number of patients tend to decline over time, and that there is also a negative association with *UNEMPL*.

For the MMJ (quarterly) revenue in a county, an additional MMC is associated with between $157000 and $222000 in additional sales (depending on the estimator) and the coefficient in each case is statistically significant. At the same time, an additional RMS reduces the medical sales revenue between $14200 and $57000, and again the coefficient is statistically significant. Compared to the sample median of *REV_MED* ($1.0m), this amounts to 1.4 to 5.7 percent, and 4.5 to 14 percent for the 25th percentile ($0.4m). At the sample means, the elasticity is -0.04 (i.e. a 10 percent increase in the number of RMSs would lower the medical sales by 0.4 percent). As an alternative measure – the ratio of the coefficient on *#RMS* to *#MMC* is for the different estimators approximately 0.1 and 0.3, suggesting that between three and 10 RMSs would reduce the MMJ sales as much as one MMC would increase it.

Turning on table 5, the coefficients on *#MMC* in the *REV_REC* regressions are negative and statistically significant, and again suggest that there is some limited degree of substitutability between the two segments. At the sample median, adding one MMC would reduce the sales of RMJ by 3 to 10 percent; at the sample means the elasticity is -0.14 and -0.55 for the two estimators, respectively. Alternatively, looking at the ratios of the coefficients, adding two to ten MMCs would decrease the RMJ sales as much as adding one RMS would increase it.

The overall sales is increasing in both *#MMC* and *#RMS*, and the point estimates indicate that sales at the latter is three to nine times higher compared to the former. Although the previous regressions showed some degree of displacement, this is evidence that the increase in the number of outlets has expanded the overall market. For instance, the difference estimator

indicates that another MMC would add $49000 and one more RMS $193000 of marijuana sales, or 1.6 and 6.0 percent at the sample median ($3.1m).[19]

Regressions with per capita patients *(PAT/POP)* and revenue in segment (*REV_/POP*). We now normalize *both* the number of patients *and* the sales in a segment with the population in the county, which allows us to relate the per capita demands to factors that are *a priori* plausible. Table 6 and 7 give the results.

For *PAT/POP*, the effects of *#MMC* and *#RMS* have the same direction of the regression which was not normalized, whereas the density of MMCs, *#MMC/POP* has a positive effect on the number of patients per capita. TIME and UNEMPL are also negatively associated as before.

With *REV_MED/POP* as the dependent variable, the coefficient on *#RMS* is negative and statistically significant in all specifications. However, the economic significance of the effect is limited – at the sample median ($19.3) an additional RMS would be associated with a reduction in the sales of MMJ per capita by 0.1 to 0.7 percent; at the sample means the elasticity is -0.12 for both specifications. The positive and significant coefficient on *#MMC* can be interpreted as showing that greater accessibility of medical outlets tend to increase sales; at the sample median an additional MMC would increase sales by about 2 percent. Supporting this notion, using a change in the density measures *#MMC/POP* and *#RMS/POP* indicates that an increase in the density of MMCs has a positive effect on sales per capita, and that the reverse is true for an increase in the density of RMSs.[20]

Among the controls, the negative and significant time trend shows that the medical sales tend to decline over time, and that *UNEMPL* is negatively associated with higher sales per capita in both. The other controls are not statistically significant.

Turning to the regression with *REV_REC/POP* as dependent variable, we find a statistically negative significant effect only from *#MMC/POP* in the difference specification. Unemployment is still negative associated with higher recreational sales per capita.

Finally, the overall sales of marijuana, *REV_TOT/POP* is increasing in both *#MMC* and *#RMS and #RMS/POP*. Both counties bordering other states and those with large leisure industries

[19] As a robustness check, we have excluded the five largest counties and the results are similar to those that reported above. Results are available upon request.
[20] Replacing *#MMC* and *#RMS* with *#MMC/POP* and *#RMS/POP* in the random effects and fixed effects estimation gives coefficients that have the same signs and largely the same significance as those reported. Results are available upon request.

have consistently significantly higher sales per capita, supporting the idea that seasonality and out-of-state demand are affecting sales of marijuana.

Regressions related to the number of outlets (*REV_ /#_*). The results in Table 8 with *REV_MED/#MMC* and *REV_REC/#RMS* as dependent variables, reveal that there is significant within segment substitutability. More outlets within the segment lowers the sales per dispensary for both RMSs and MMCs, which is inconsistent with a free entry model but in line with the predictions from a model of restricted entry. Moreover, the negative time trend in the sales per MMC is not consistent with a free-entry model but might be related to excessive entry once the RMS entered – an MMC that has already entered and sunk some costs might remain, even though its demand is declining.

That ln(*POP*) is positive and significant for both random effects regressions could either be interpreted as the combined effect of higher operating costs in more populous counties, or that per capita demand is higher in these areas. The positive and significant coefficients on *BORDER* and *LEISURE* (only in the *REV_REC/#RMS* estimation) support the above assertion about the importance of out-of-state demand.

Regressions related to sales per patients and patients per MMC (*REV_MED/PATIENT*, *PATIENT/#MMC*). The final results relate to normalizations with the number of patients, and can be found in Table 9. The positive coefficient on *#MMC* is consistent with larger number of outlets spurring sales. However, the fact that *#RMS* is also positive and significant in the random and fixed effects specifications appears to be at odds with the former. Here, an interpretation of the negative coefficient in the difference specification is that the number of patients shows a slow response to market structure – increasing *#RMS* would not immediately influence the number of registered patients but will result in some of these to turning to RMSs. Thus, an increase in *#RMS* will reduce the sales per registered patient. Note also that the constant term in this specification suggests that medical sales per patient are increasing over time.

The controls are in line with the interpretations above – the in-county registered patient underestimates the true demand, given that some sales are to out-of-state buyers.

The final part of the results suggests that the number of MMCs relative to the number of patients is declining over time. To make this consistent with the results reported above, the sale

per patient is increasing but their numbers are decreasing. In other words, there are fewer patients but those that remain tend to be buyers of larger amounts.

3.1.3. Summary of Econometric Results

The evidence presented thus far is consistent with a statistically significant but economically limited displacement effect. The evidence suggests that the emergence of RMJ had a modest effect on sales in the medical segment and that the marijuana sales tend to fragment, such that customers with large demands continue to purchase from the MMCs but other, marginal users switch to the RMSs when available.

The estimation is subject to heterogenous treatment effects. For instance, the effect of the opening of RMSs on MMJ sales may have been stronger in counties that were more geographically distant from counties where RMSs were operating. Other differences relates to the timing as it is possible that the effect was stronger during the first quarters of operations of RMSs. Future estimation looking at the effect on a longer time period are needed to confirm the magnitude of displacement effect.

3.5. Conclusion

In this paper, we have examined how sales at licenced medical marijuana centers (MMCs) in Colorado were affected by the opening of retail marijuana stores (RMSs) in 2014. Our results suggest that although the two types of outlets may cater partially to the same marijuana demand, allowing RMSs has had only a modest negative effect on sales at the MMCs. Using a variety of estimates, our conclusion is that medical sales decreased by about 10 percent at most, and likely only in the low single digits. The fact that the sales of recreational marijuana have increased dramatically since 2014 indicates that the main effect of legalization has been market expansion, rather than displacement of medical sales. The number of registered patients has been decreasing since the inception, but sales per patient increasing. This implies that some occasional users who may have previously purchased at an MMC have now shifted to RMSs. It is plausible that some of these occasional users had a recommendation for marijuana, although the main use was for recreational purposes, and that the introduction of RMSs has discouraged this abuse.

Our findings indicate that medical and recreational marijuana outlets can co-exist, but it seems likely that the lower taxation of the medical variety is an important reason behind this. There is overlap in the product offerings at the two, but as recreational marijuana stores can sell to any adult, it is difficult to see other reasons for sales in the medical centers, other than the lower

price that comes from lighter taxation. This differential in taxation have lead some (see e.g. Caulkins et al., 2016) to consider MMCs as "tax-evasion machines" and the whole medical program as friction, limiting the ability of the state to collect the maximum possible revenues (e.g. Washington state collected 25 percent more tax revenues per resident in its third year of legalization by integrating the medical and recreational market). However, if one argues that use of marijuana for medical reasons should be treated differently from non-medical use, the evidence presented here reveals that even relatively small tax differentials will separate the user segments. Those requiring large amounts of the product for medical reasons will tend to use the MMCs, while less regular users will purchase from RMSs.

Our finding of a sharp and sustained increase in sales of recreational marijuana coupled with the very limited displacement of the medical marijuana sales begs the question: if sales were displacing illicit marijuana, has this had any effects on the use of alcohol and other substances?[21] Using the same methodology as here - exploiting the county differences in the accessibility of legal marijuana –available data on alcohol sales could be used to estimate the effect on sales in that market from legalizing medical and recreational marijuana.[22] In the absence of county level data on sales of illicit marijuana, any attempt to judge the extent that introducing RMSs replaced the illicit trade would have to rely on indirect measures, such as demand-based or expenditure-based surveys.[23] If the legalization of recreational marijuana completely replaces the illicit trade, the prediction is that changes in observable use measures would be less dependent on changes in legal access; the lower the replacement, the more responsive the observable use is for increasing the accessibility of legal sales. Finding observable measures of marijuana use and other outcome variables – at a county or other local

[21] There is a consensus that legalizing MMJ has reduced the number of prescriptions drugs (Bradford and Bradford, 2016), opioids (McMichael et al., 2020; Wen et al., 2021) and individuals abusing painkillers (Bachhuber et al., 2014; Powell et al., 2018).

[22] Baggio et al (2020) use county level data on alcohol sales and found a 12% decline in alcohol consumption in states where MMJ has been legalized, but does not consider that the accessibility of MMJ may well differ within a state as Colorado. Moreover, it is likely that the effect would be stronger for RMJ than for MMJ.

[23] There is reason to believe that the RMSs has significantly reduced the illicit trade. Light et al. (2014) estimated that during the first year with both MMCs and RMS, the total use of marijuana (legal and illicit) would be 130.3 metric tonnes, out of which 54.8 and 22.2 metric tonnes sold at MMCs and RMSs, respectively, implying a nonregulated use of 58.3 metric tonnes, out of which between 5.0 and 20.6 metric tonnes could be accounted for by home grown marijuana. This implies that the illicit (black market) marijuana trade was between 33 and 48 metric tonnes. Since then the medical sales (in revenue terms) have remained roughly at the same level but recreational sales has increased by 120 percent (in revenue terms) which, assuming constant prices, would imply that the equivalent of an additional 26 metric tonnes or between 55 and 80 percent of the illicit quantity as of 2014.

level – and relating these to legal and medical outlet access is a promising future direction for future research on the effects of marijuana legalization.

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3.7. Appendices

APPENDIX TABLE 1.
Summary statistics for selected characteristics

	Characteristics	Sample counties	Other counties
Patients	Patients (2009)	0,16%	0,16%
	Patients (Jun-2011)	4,74%	2,69%
	Patients (Jun-2017)	2,29%	1,69%
	Six years drop in patient	2,46%	0,99%
Out-of-state demand	border	33%	45%
	Ski Resort	58%	18%
	Tourism (2017)	15,1%	10,7%
Addiction	Smoking	17,5%	17,9%
	Excess Drink	20%	16,1%
	Alcohol-driving	29,8%	28,3%
Political View	Competitive RMJ market	92%	23%
	Dem2016	49,0%	29,6%
	Ballot2012	59,7%	46,3%
Socio-economic	Student	8,02%	5,21%
	Bachelor	37,9%	24,5%
	Median income ('000)	58,22	46,88
	Mean income ('000)	77.41	60.54
	2015 Unemployment	4,07%	4,26%
	Adult Population (Million)	3,574	0,704
	#counties	24	40